MARSH

The Development and Use
Of the Chain Gate Stoker

Mechanical Engineering
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THE DEVELOPMENT AND USE OF THE CHAIN GRATE STOKER

BY

THOMAS ALFRED MARSH

B. S. University of Illinois, 1904

THESIS

Submitted in Partial Fulfillment of the Requirements for the

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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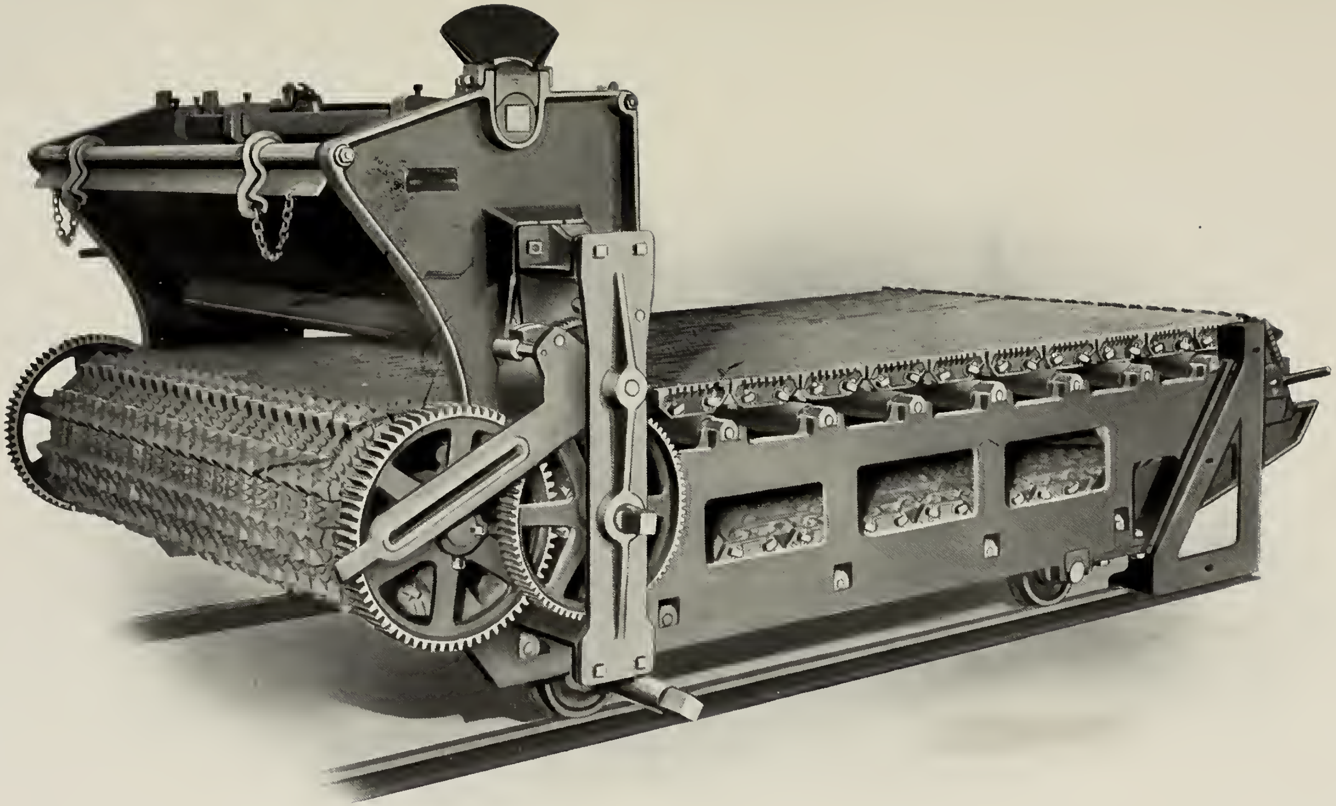
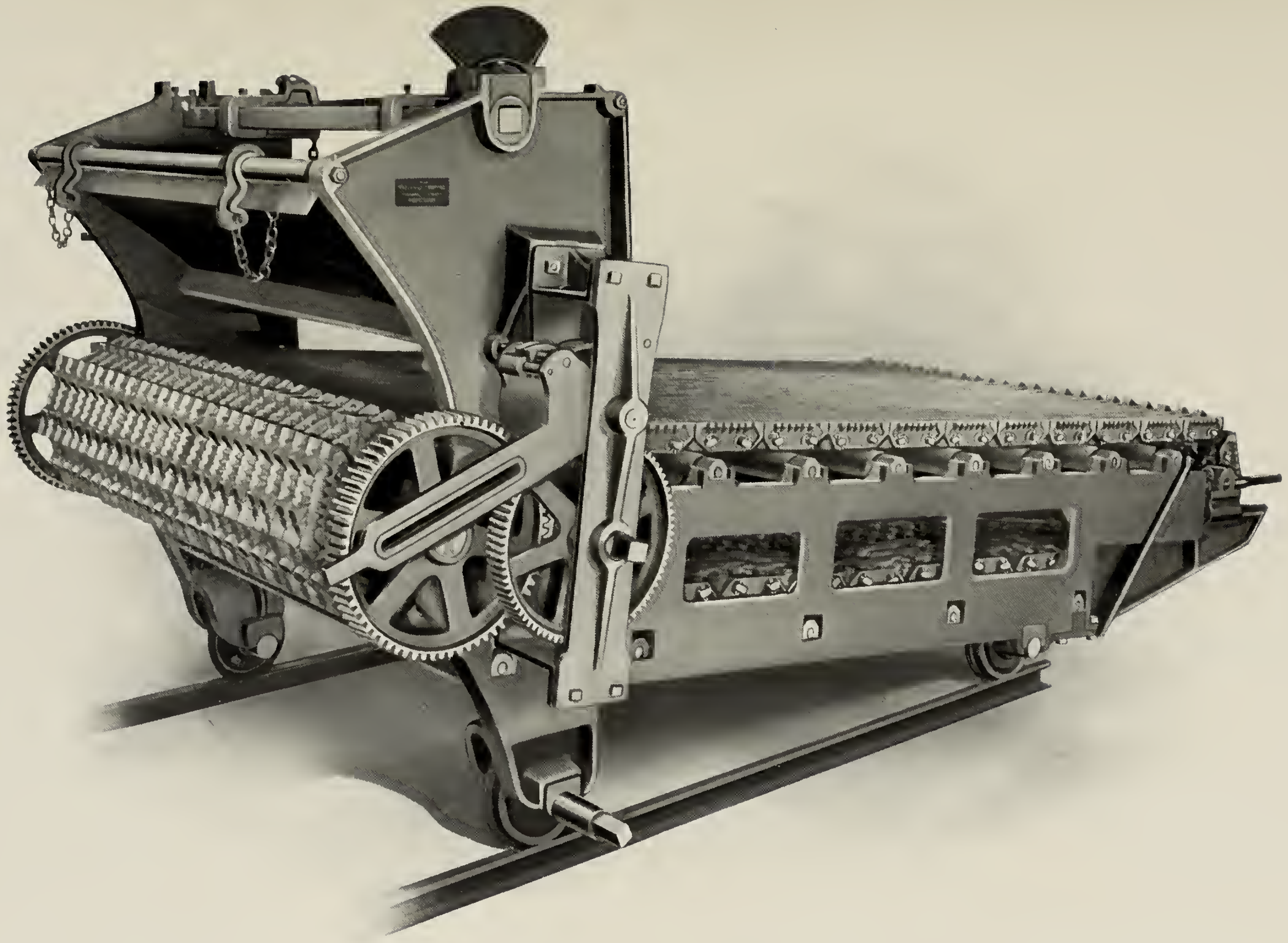


HORIZONTAL CHAIN GRATE STOKER



INCLINED CHAIN GRATE STOKER

THE DEVELOPMENT AND USE OF THE CHAIN GRATE STOKER

INTRODUCTION

With the rapidly increasing number of installations of the various types of Mechanical Stokers, specific literature regarding each type is in demand. The bulk of the present literature regarding Chain Grates is academic in nature, and the writer has for sometime felt the need of a paper viewing the subject from a commercial standpoint, familiarizing the reader with the ground that has heretofore been covered by research and practice, entering into the problems confronting the engineer in this field, and setting forth present-day practice both from the theoretical and operative standpoint.

HISTORICAL

The earliest Mechanical Stoker for steam boilers was probably designed by James Watt in the year 1785. The mechanism was simply a device to push the coal, after it was coked at the front of the grate, back toward the bridgewall. The suggestion of Watt was followed by numerous patents in Europe for Mechanical Stokers, but none of these have been adopted to any considerable extent in this country, because of their supposed lack of adaptability to American boiler

practice. Their non-adoption here was partly because the mechanism was of too complicated a nature to be entrusted to the average fireman, or the rate of speed at which the machine would be required to run was such that it would be wanting in durability. Another objection was, that in many cases the grates were so placed as to be almost inaccessible either for examining or altering the condition of the fire by hand, or for renewing worn-out parts.

The Chain Grate was one of the types originating in England from Watt's experiments. In its early stages it was exceedingly unmechanical, having parts not readily renewable, exposed to the heat, and very poor mechanism for driving and adjusting.

The earliest record in this country of a Mechanical Stoker of the progressive-feed type of which we have any record, is one of the traveling grate-bar type designed by Royal F. Weller, of Albany, N. Y., in 1871. As an improvement on this type of grate, Simon Regan, in 1877, designed the first Chain Grate on record, the design having much in common with the Chain Grate of the present time. During the ensuing fifteen years many improvements were made in mechanical details, particular attention being called to the work of Eckley B. Coxe, of Drefton, Pa., who did much pioneer work in designs of Chain Grate details between the years 1892 and 1895. Mr. Coxe designed the removable feature of stokers mounted on truck shafts, and also is largely responsible for the develop-

ment of the igniting arch. During the period from 1895 to 1900 much was done to eliminate the unmechanical feature both of the stoker itself, and of the construction of the furnace, the patents taken out during that time being largely for types of grate bars and stoker details.

Among those who have developed the most popular types of Chain Grates now on the market, the following names should be mentioned:

Name of Company	Names of Patentees
The Green Engineering Company	Mr. W. M. Green
	Mr. J. R. Gent
	Mr. H. A. Poppenhusen
	Mr. Joseph Harrington
The Babcock & Wilcox Company	Mr. J. E. Bell
The American Stoker Company	Mr. F. Girtanner
The McKenzie Furnace Company	Mr. Dougal J. McKenzie
The Playford Stoker Company	Mr. Geo. Playford, Jr.
	Mr. Charles J. Allen
	Mr. Frank R. Tibbitts

DEFINITION OF TERMS AND PHRASES

In order to facilitate the understanding of the ensuing pages to the reader unacquainted with the commercial terms, the following definitions of words and phrases are presented, together with a side elevation of a Chain Grate (Fig. 1) the names of many parts of which are indicated thereon.

CHAIN: The assembly of links on bars forming the grate on which the fuel rests.

LINKS: The component parts of which the chain is composed.

COAL HOPPER: The receptacle or reservoir containing the fresh fuel being fed into the furnace.

FURNACE: The chamber in which combustion of the gases is completed.

GATE: The mechanism by which the thickness of fuel bed on the grate is regulated.

LEDGE PLATE FLANGES: Cast iron plates jambing closely against the sides of the chain throughout its length in order to shut off the air leak.

BRIDGEWALL: A wall at the back end of the grate to direct the current of the draft.

BRIDGEWALL OVERHANG: The projecting portion of the bridgewall extending over the chain.

WATERBACK: A pipe placed at the extreme end of the bridgewall overhang through which water circulates. Its function is to make an air seal easily maintained,

and to which clinker will not adhere.

INTERNAL DAMPER: An arrangement inside of the chain meeting both the upper and lower leads, and making, with a wall below and the waterback above, a complete air seal through the machine.

COKING AND IGNITING ARCH: An arch of fire brick or fire tile extending from the front of the furnace backward for from 3 to 6 feet.

ARCH TILE: Special fire brick tile of which some arches are constructed.

INSPECTION DOOR: The door through the side wall of the furnace through which the fire is inspected.

ASH HOPPER: A receptacle below the floor at the rear of the grate to receive the ash and refuse.

DROPPAGE: Unburned coal which passes through the interstices of the chain to the receptacle below.

BAFFLE: A wall or partition erected to direct the passage of the hot gases through the boiler.

DESIGN OF THE STOKER

The fundamental purpose of the stoker is to convey an even bed of fuel into the furnace within certain limits of thickness of fuel bed and rate of travel.

The fuel thickness must vary from 0 to 10 in. and the rate of travel from 0 to 6 in. per minute.

The chain is designed of short links from 8 to 12 inches in length, from 1 to 1½ inches in width, and weighing approximately 10 lbs., strung in staggered formation upon transverse bars, the whole creating a web which travels over sets of sprockets, thus forming a horizontal grate surface.

The thickness of fuel bed is regulated by a gate which is raised and lowered by some suitable mechanism, usually a worm and sector. Different heights of gate permit different thicknesses of fuel bed to pass thereunder. Gates are made of cast iron, or preferably steel, I beam frames into which fire brick tile are fitted, presenting a face of fire brick to the furnace. The Playford Stoker is equipped with a gate having a water circulation therethrough, but the heat requirements are not sufficiently severe to demand such precaution with all the mechanical troubles incident to a contrivance of this nature in ordinary practice. However, when burning such highly inflamable fuels as sisal from twine mills some such device is imperative, as the fuel ignites back into the hopper, burning the usual type of gate in a short time.

It is of material assistance in operating to have accurate

indicators registering the gate heights on each stoker.

The rate of travel is regulated usually within small limits by a slotted feed lever driven from an eccentric shaft, and beyond such limits by means of the governor of the driving engine or rheostat in case of a motor driven installation. It is customary to have a 400 per cent regulation of speed on the machine itself, which is ample provision for the normal installation.

An adequate amount of air must be provided for complete combustion at the highest required rating, but the air spaces must be such as to prevent an excess of fine coal sifting through the grates, as this action destroys the uniformity of the fuel bed and necessitates additional labor in rehandling. The usual proportion of air space in Chain Grate practice is 20 per cent of the entire grate surface, which with the present rates of combustion requires that the air entering the furnace through the grate shall travel at approximately 3 to 10 feet per second, which is well within the limit of allowable velocity for entering air.

The calculation of the velocity of the air entering the furnace is as follows:

1 lb. of carbon requires 11.3 lbs. of air for complete combustion. Assuming 100 per cent excess air, 1 lb. of carbon requires 22.6 lbs. of air. Assuming coal to be 80 per cent carbon, 1 lb. of coal requires 18.08 lbs. of air.

The usual rates of combustion are from 10 to 30 lbs. of coal per square foot of grate surface per hour.

10 lbs. of coal at 18.08 lbs. of air per pound, requires 180.8 lbs. of air.

Volume of air per lb. = 13 cu. ft.

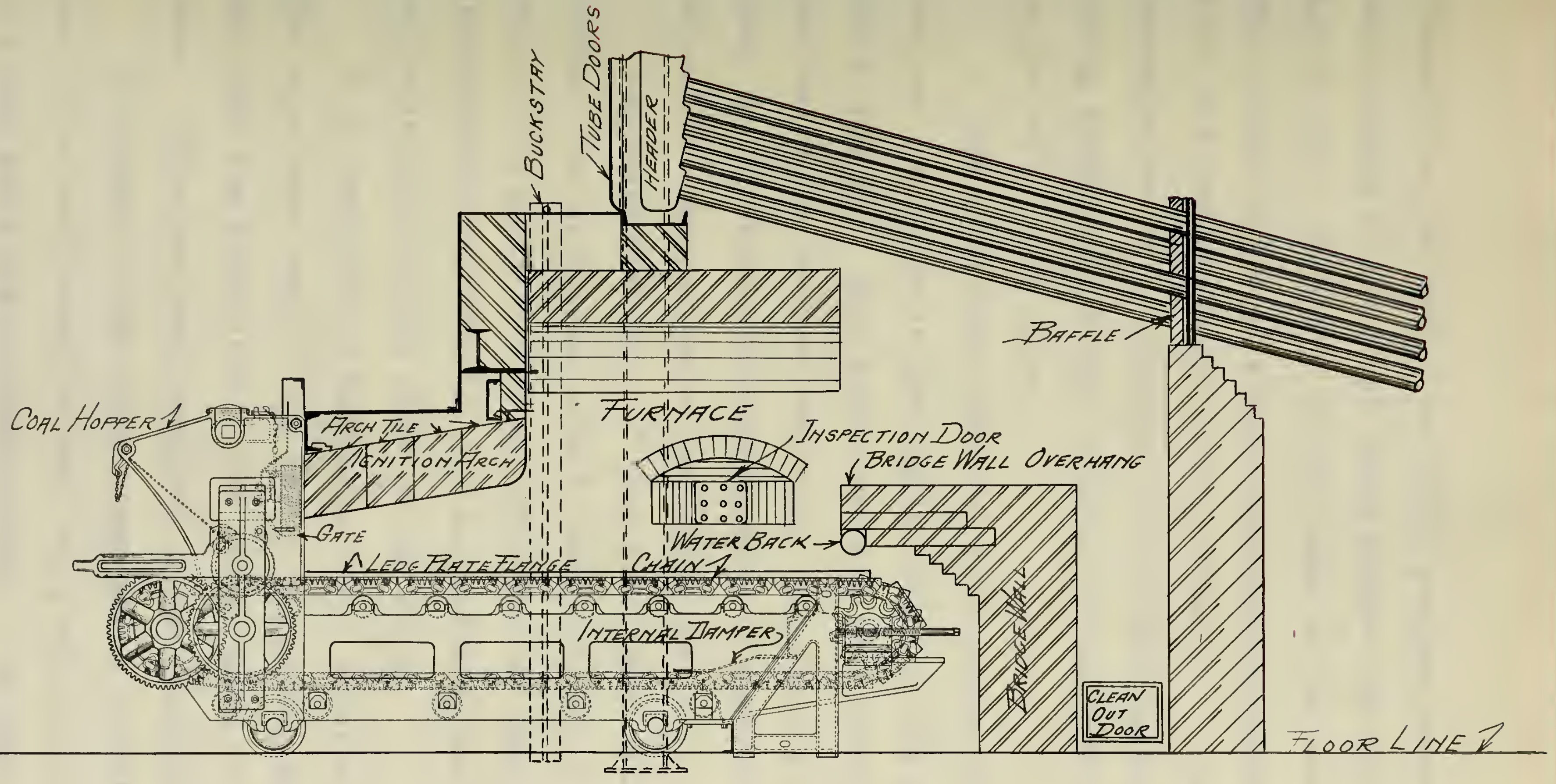
Hourly air = 2350 cu. ft.

With 20 per cent of air space and combustion rate of 10 lbs. per square foot of grate surface per hour, the velocity of the air = 3.2 feet per second. Based on 30 lbs. of coal per square foot of grate surface per hour, the velocity of the air = 9.6 feet per second.

Links having 20 per cent air space do not permit an excess of fine coal to pass therethrough, the average portion of droppage of slack coal through grates of such design being 10 per cent of the amount fired.

The writer has experimented with a larger per cent of air space but has been unable to note any change in conditions other than a marked increase in the per cent of droppage.

Adequate air supply through the fuel bed, of course, implies that no air shall enter from other sources. This necessitates that suitable flanges project from the furnace walls to the sides of the chain, thus cutting off air leaks from that source, and that there shall be a system of transverse baffling at the rear of the stoker preventing air from short-circuiting around the end of the grate and thus entering the furnace. This is accomplished by means of an internal damper (Fig. 1) which, with the waterback above the grate and a suitable damper plate or wall below, effects a complete air baffle, thus causing all air entering the furnace to pass



LONGITUDINAL SECTION OF CHAIN GRATE FURNACE

FIG. 1

FIG. 1.

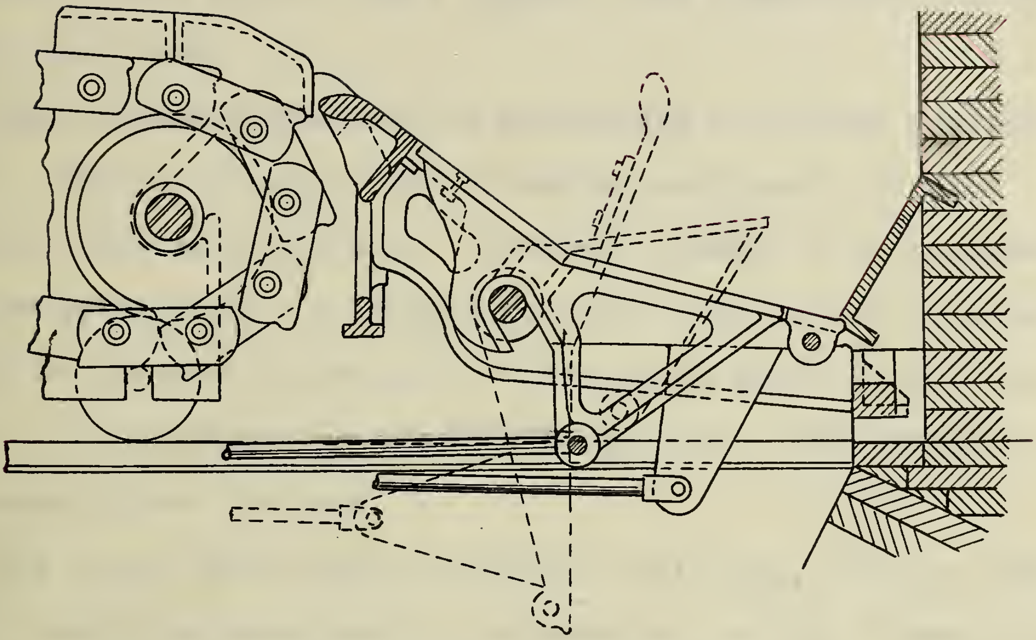
through the fuel bed. Carefully designed stoker chains now have flanges on the links which prevent the horizontal passage of air. This item of air leaks at the rear end of the Chain Grate is one of great importance, although until recently it has been given but little attention. Considerable economies are being effected in old installations by introducing effective dampers, cutting off the inrush of cold air at the rail of the grate.

A type of air seal that has been extensively tried during the past two years is the dumping plate at the end of the grate (Fig 2). This device has met with little success for the reason that unless generously ventilated it will soon burn, and if ventilated sufficiently to prevent burning, it defeats its own purpose of excluding free air.

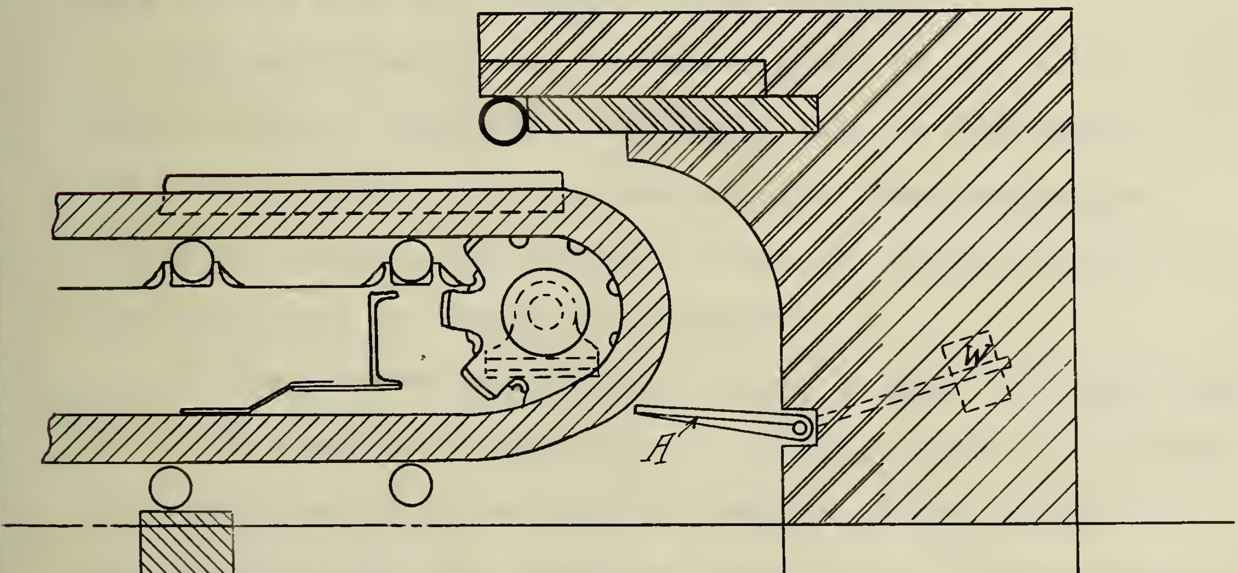
Ash retainers (Fig. 3) have been tried with little success, the principle being to hold sufficient ash at the rear of the grate to make an effective air seal. The main difficulty arises from hot ash accumulating and burning off the projections of the links of the chain.

F. H. Richards,of Hartford, Conn., secured patents in 1895 on a water seal at the end of the grate, embodying the idea that the lower lead of the stoker chain be immersed in water. This was soon abandoned as unmechanical.

On account of the rough usage due to location and attendants, it is very essential that all parts of the stoker be of a very solid and permanent nature. No frail mechanism can exist under the conditions.



DUMPING PLATE FOR CLINKERS
FIG 2



ASH RETAINER
FIG 3

All complicated designs must be avoided, as the operator is often called upon to make repairs, and simplicity may prevent a shut-down.

All exposed parts must be adequately protected from the heat. This is usually done by making such parts of fire brick or similar materials. However, should it be necessary to have metal parts in exposed positions, an air circulation should be forced around such parts by the draft in the furnace. If possible, such parts should have small readily-removable plates thereon.

All parts that require frequent replacing, such as chain links, should be made readily replacable, and all large parts, so far as possible, should be made of standard rolled sections in order that in emergencies they may be purchased locally, thus saving time and transportation charges.

The more readily the operative parts of the stoker and furnace may be inspected, the better will be the success of the installation. To this end all gears and mechanisms should be exposed, and adequate doors put in the furnace for the inspection and repair of brickwork.

In the present day competition is so keen that low shop costs are absolutely essential. Stokers have been designed and redesigned with the idea of minimizing the amount of machine work, and thus reducing shop costs. Castings must replace small steel parts, and these castings must be so designed as to readily lend themselves to moulding machine work.

Parts must be so designed and finished as to go together easily in the field, for any delay on this end runs into large items. It often occurs that certain parts may be modified in some manner, thus minimizing the work in the field. To this end suggestions from erectors are considered and discussed, and many good points of design have sprung therefrom.

ARCHES

The fresh coal entering the furnace is ignited by radiation, or rather by the reflection of the heat from the hotter central part of the furnace to the front thereof. This is accomplished by means of an arch set approximately 12" above the grate surface in front, and extending back over the grate. With coals containing 30% of volatile it is customary to give a length of three feet and a slope of 2 inches per foot to this arch. With coals containing a smaller percent of volatile and higher ash, and for that reason being more inert, a stronger ignition effect is required. To accomplish this it is necessary to increase the length of the arch, set it more nearly horizontal, or both. The various types of boiler settings require special designs, which will be more thoroughly discussed in a succeeding chapter.

Arches are of two styles:- (a) Sprung Arches; (b) Suspended Arches.

Sprung Arches are successful in narrow settings (not exceeding six feet in width). Beyond this width there is so large a difference between the maximum and minimum distance

of the arch from the grate as to affect the ignition when certain coals are used. Beyond the width of eight feet the sprung arch, unless given a very ample rise, is very impracticable as a maintenance proposition, as the thrust upon the side walls is very excessive.

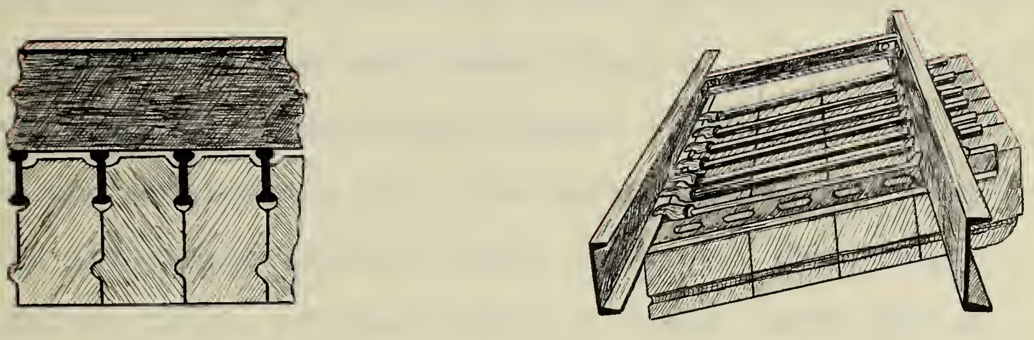
Suspended Arches are made of special shaped tile supported on a framing from above. Figure 4 shows the suspended arch used by the Green Engineering Company. This type of arch has the advantage of having equal height from the grate and every point in a transverse section, which gives uniform ignition and combustion at all such points.

Another type of arch is the Jack Arch recently designed and shown in Figure 5. This arch embodies certain features of the suspended and of the sprung arch. It does not overcome the thrust effect of the ordinary sprung arch, but it presents a plane surface to the fire, and avoids the necessity of metal framing for its support.

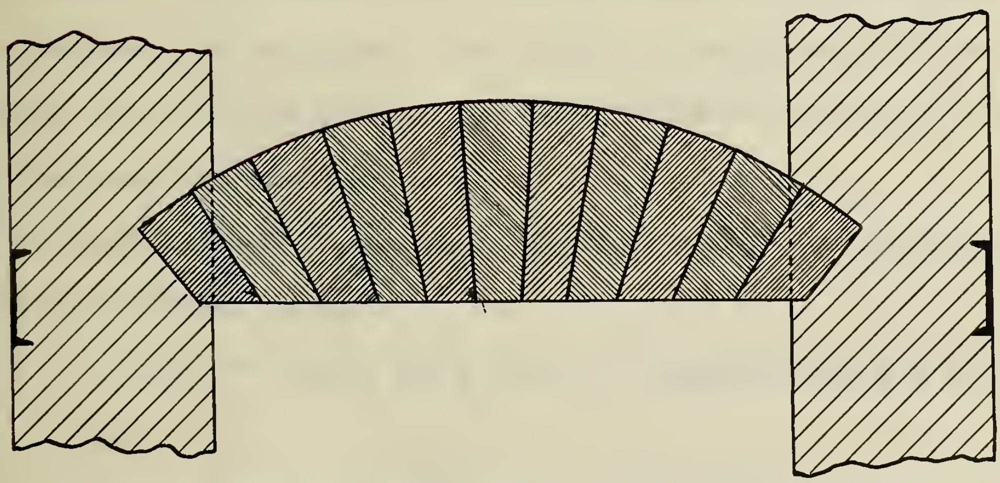
WATERBACKS

The function of the waterback is to prevent the inrush of cold air around the end of the grate, and to present to the fire a cool metal surface to which clinker will not adhere. It is also an excellent feature for maintenance of bridgewall overhang.

There are two general classes of waterbacks in use at this time, those in the circulation of the boiler, and those having a separate water circulation. The former type is



FLAT SUSPENDED ARCH
FIG. 4



FLAT SPRUNG ARCH
FIG. 5

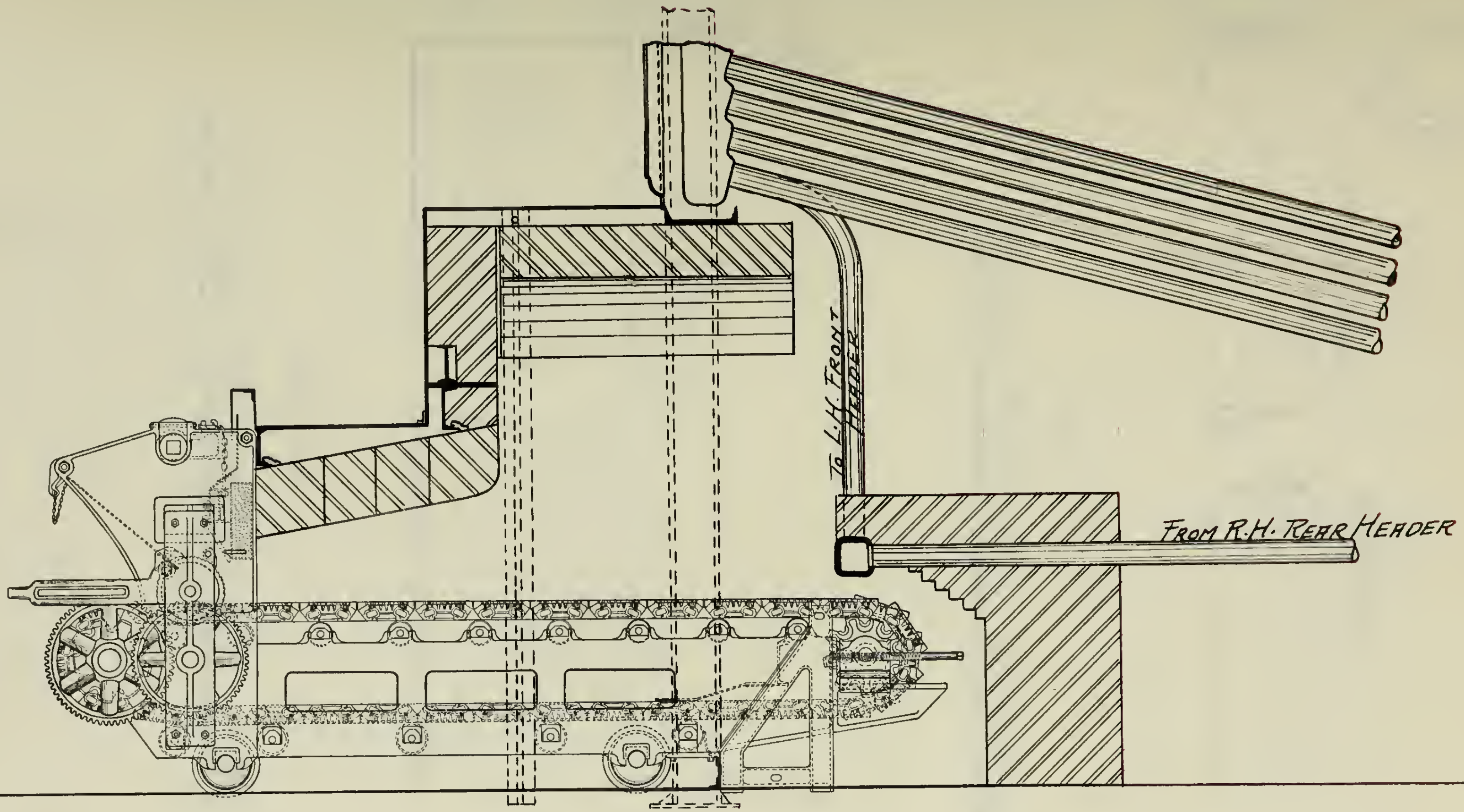
usually designed as a steel box rectangular in section, being connected on one end to the front header of the boiler, and on the other end to the rear header (Fig. 6). This class of waterback requires frequent and regular blowing down to remove mud and settlement, and it is advisable only in plants where the proper care will be taken thereof. The Commonwealth Edison plant, at Fisk Street, Chicago, have many of this type, giving excellent service, as have also the City of Chicago Pumping Stations, but it must be borne in mind that this type of waterback invites all of the troubles inherent to pressure parts under the most severe conditions, and for this reason discretion should be used in recommending such design. In installing these waterbacks valves must be so located as to permit the proper blowing out of the pipe, and also the cutting out of the same from the boiler circulation, in case of burning out.

Of the class of waterback having separate circulation, there are several types:-

1. Plain 4" steel pipe with 1" circulating pipe (Fig. 7).

2. Cast iron waterback with circulating pipes cast therein (Fig. 8).

The plain steel pipe is the more preferable under ordinary conditions, it being a readily renewable part, easy of access for cleaning, and if slightly warped may be turned 90 degrees in the brickwork without removing it from the furnace. The end connections are made reversible for this



WATER BACK IN CIRCULATION OF THE BOILER

FIG 6

FIG 6

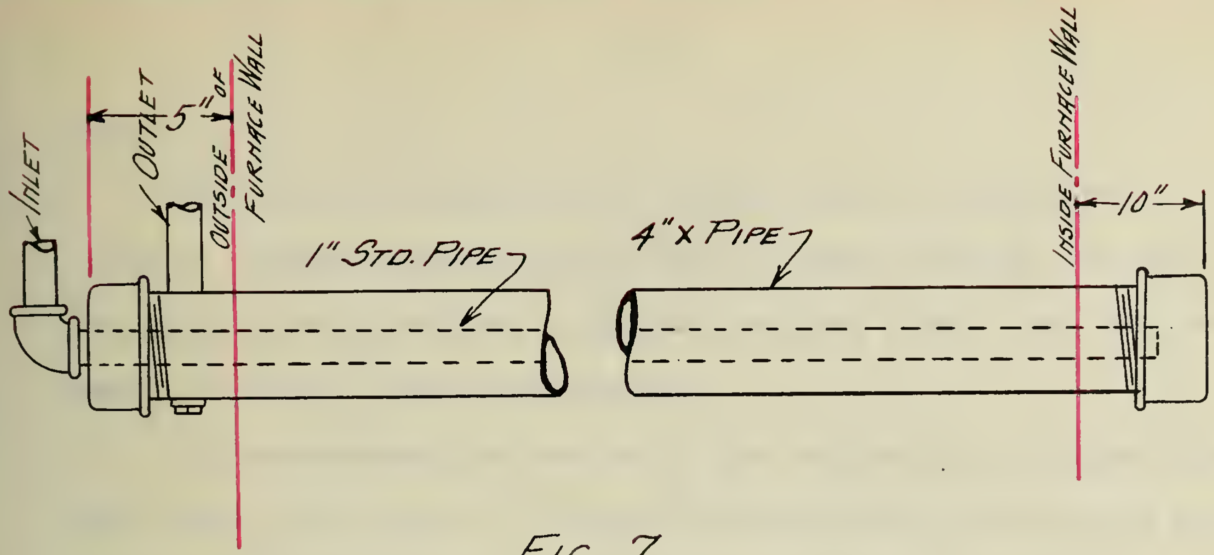


FIG. 7.
PLAIN STEEL PIPE WATERBACK

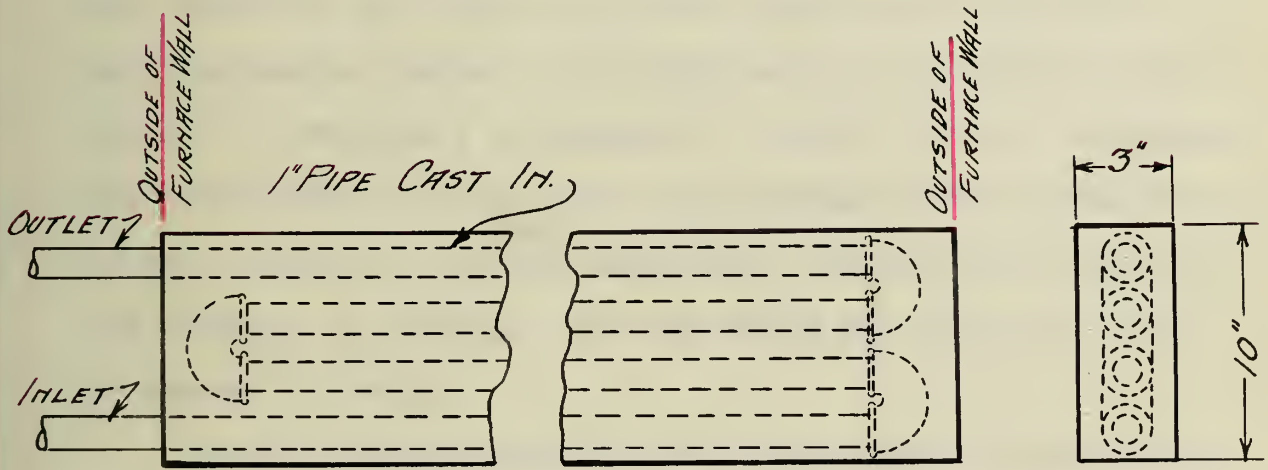


FIG 8
CAST IRON WATERBACK WITH 1" PIPE CAST IN.

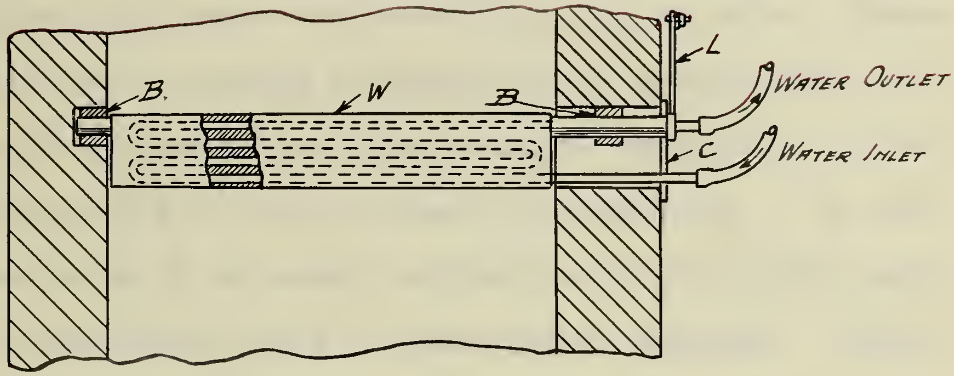
purpose.

The cast iron section is stiffer but is difficult to clean. These are often cast with a chain through the circulating pipe which may be drawn back and forth, and the removal of scale thus accomplished.

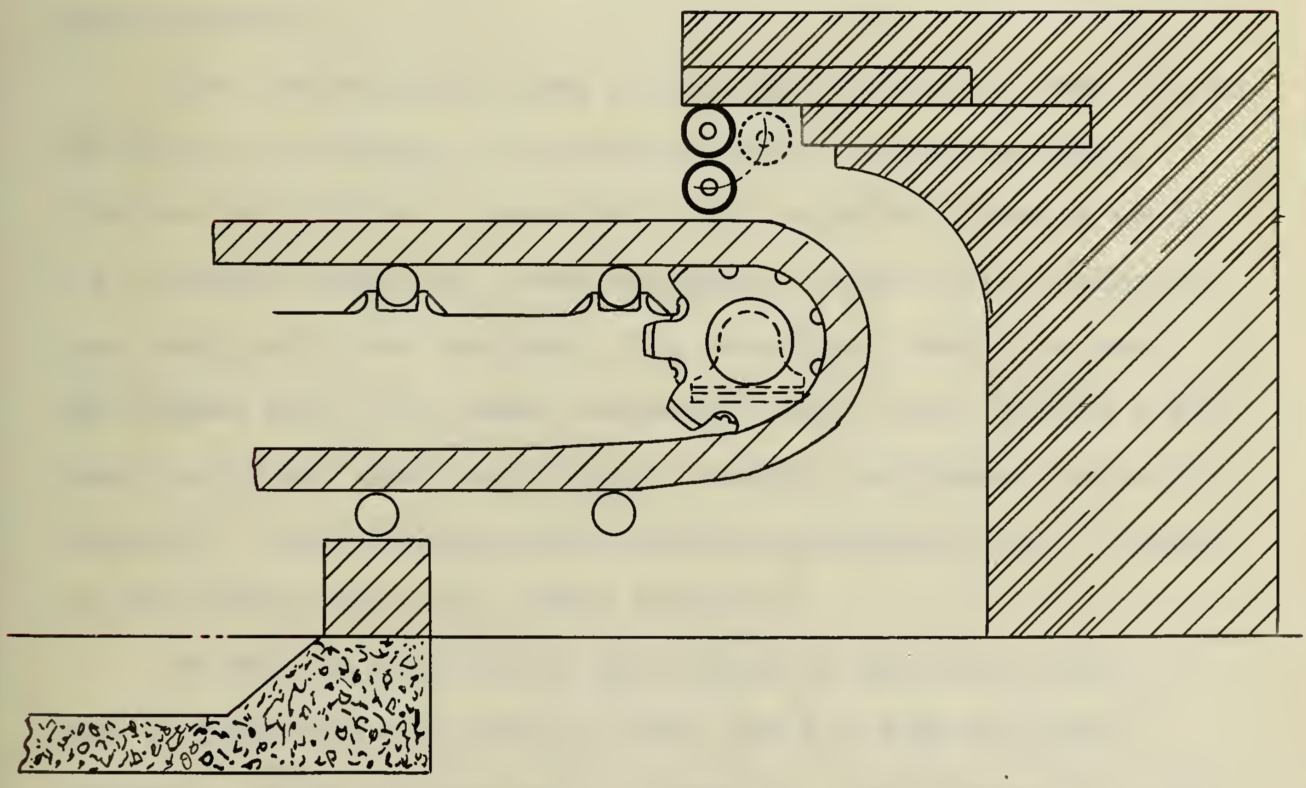
All waterbacks are set with the outlet end ½" lower than the inlet, in order to prevent the possibility of an air pocket, and the consequent burning out of the waterback.

Waterbacks having an adjustable distance from the grate surface have given excellent results as regards cutting off the inrush of air, but it has been found very difficult to maintain moving parts in the extremely high temperatures to which this waterback is exposed. Of this type of waterback the best known are the Harrington Automatic Waterback, designed and patented by Joseph Harrington, of the Green Engineering Company, of Chicago, and the Junge Waterback, designed by George L. Junge.

The Harrington Automatic Waterback shown in section in Figure 9, is composed of two 4" pipes arranged parallel about 6" from center to center, the upper one being stationary and the lower one swinging around the upper as a center, varying its distance from the grate surface from 2" up to 7". The Junge Waterback accomplishes the same result by means of a rectangular section and having cast therein a copper circulating pipe. The casting is pivoted from the upper ends and when swinging varies the net opening between itself and the grate surface. A front elevation of the Junge Waterback is



THE JUNGE AUTOMATIC WATER-BACK
FIG. 10



THE HARRINGTON AUTOMATIC WATERBACK
FIG 9

shown in Figure 10.

The ideal position for a waterback is to have it set so the layer of ash caused by the complete combustion of the fuel will just pass under the waterback, but no more. Under these conditions the refuse is permitted to escape, but the inflow of cold air under the waterback, or escapement of unconsumed coal on top of the ash bed, is prevented. If one grade of coal were to be used, and one rating of boiler maintained, this condition could be very nearly secured. While under practical conditions this is impossible, it should be the aim to get this result as nearly as possible. Assuming normal drafts and normal rating of boiler, which in turn necessitates normal thickness of fuel bed, the following is good practice.

With coals having from 10 per cent to 15 per cent of ash, in which is probably included the major portion of Ohio, Indiana and Illinois screenings, the waterback should be 3 to 4 inches above the grate surface. With coals having 15 per cent to 25 per cent ash, the waterback should be set 4 to 4½ inches above the grate surface. With coals having 5 per cent to 10 per cent ash, which includes the washed coals of Illinois, the waterback will operate satisfactorily 2 inches to 2½ inches above the grate surface.

It will be noted that the height of the waterback is not in proportion to the per cent ash for the following reason. With a given draft intensity, the cleaner the coal, the thicker is the fuel bed that may be economically burned.

While the per cent of refuse may be doubled or tripled in the coal, this figure is partially offset by the fact that with such coal the thickness of the fuel bed entering the furnace is reduced probably one-half.

In all cases the heat entering the water that passes through the waterback should be utilized. This may usually be done by piping the discharge to the hot well.

Plate X illustrates by means of a curve the per cent of heat required to maintain a waterback. The data for this curve were compiled by Mr. Henry B. Dirks, M. E., from tests made at the Experimental Station of the University of Illinois.

The difference between the temperature of the supply and discharge should be approximately 100° under which conditions the amount of water required to maintain a waterback varies from 10 to 20 per cent of the amount required to feed the boiler under which the waterback is installed.

As regards maintenance of waterbacks, the writer recommends the use of thermometers on the discharge line, and the keeping of the discharge at a fixed point about 180 degrees. The use of a thermostatic valve to accomplish this end would seem to be very feasible, if a positive, reliable instrument could be found.

ASH PITS

The ash pit must be designed to accommodate at least six hours deposit of ash at maximum rating, and one of double

such capacity is desirable. If metal hoppers are installed, they should be brick-lined and provided with spray pipes for the double purpose of cooling the ash and settling the dust that otherwise arises therefrom, and should be provided with some approved type of valve. If pits are designed from which the ash is to be shoveled or drawn, careful provision should be made to avoid any sudden steps or ledges which make the removal difficult. All slopes must be designed with a greater angle than the angle of repose of dry ashes, which is 40 degrees. It is very essential that all ash pits be equipped with close fitting doors or valves, preventing the entrance of air into the furnace from that source.

INSPECTION AND CLEANING DOORS

Each setting should have a convenient door for inspection, and of sufficient size to permit of entrance to the furnace in case of slight repairs, or of tube cleaning. This door should be set well back towards the bridgewall and slightly above the grate surface. It should be well anchored into the brickwork and provided with a cast iron liner to prevent excessive heating of the outer parts.

THE FIELD OF CHAIN GRATE INSTALLATION.

Because of the particular adaptability of the high volatile, low carbon coals of the West to this method of firing, the district of Chain Grate installations may be broadly termed as West of Pittsburgh. The coking and caking coals of the Eastern section give rise to complications, and require treatment other than that embodied in the standard Chain Grate practice of the present time. The analysis of the normal Chain Grate coal is as follows:-

Volatile------------	30 per cent
Fixed Carbon--------	55 per cent
Ash-----------------	10 per cent
H20-----------------	5 per cent
Total--------------	100 per cent

B. T. U. by Robt. W. Hunt's formula 11429

B. T. U. = (14500 x % F. C.) + (16515 x % vol.) - 10000 (% ash H_2O)

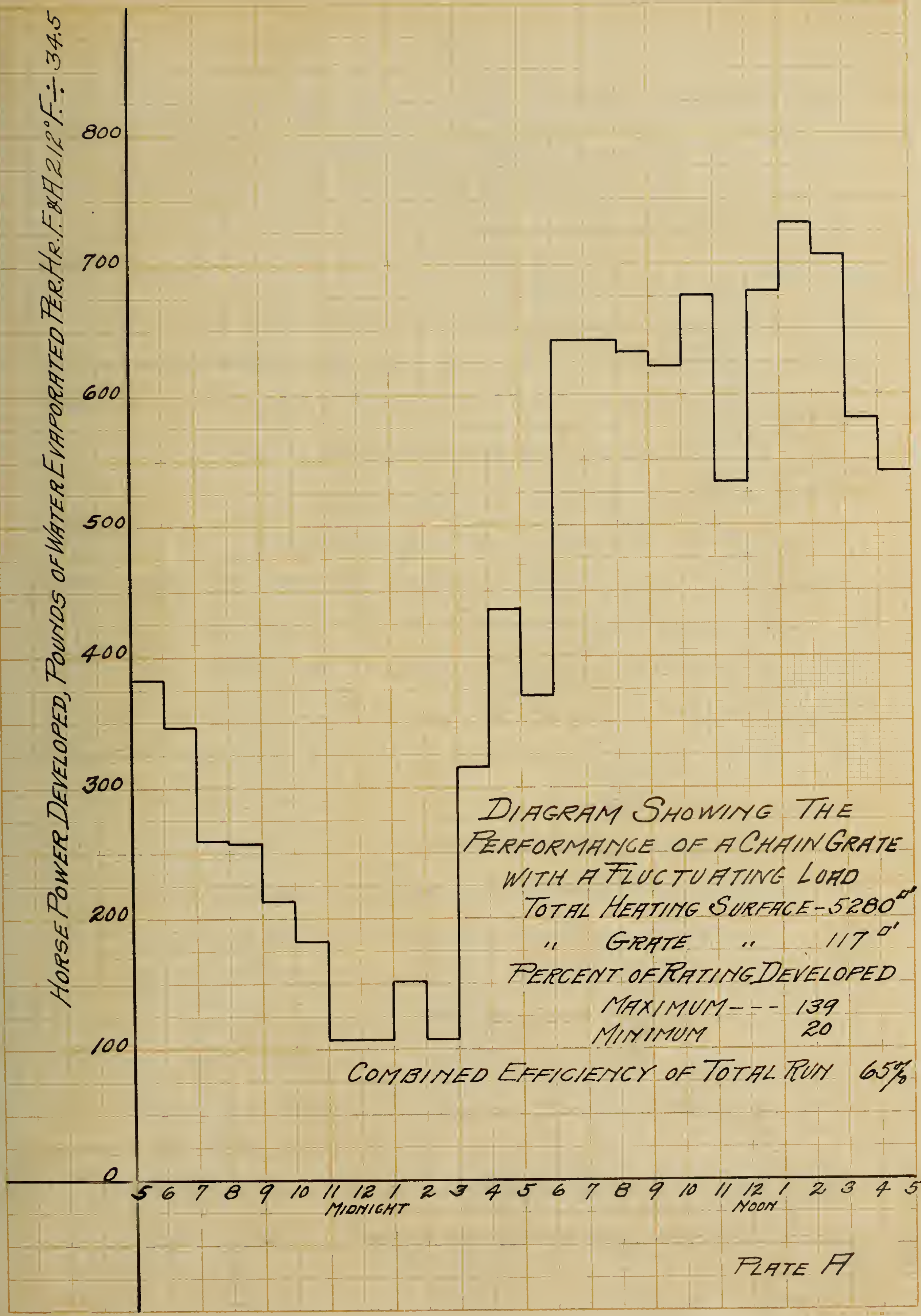
This analysis may vary to the extent of the per cent of ash reaching 30 per cent, and the volatile becoming as low as 20 per cent, but such a coal ignites very slowly, which fact, combined with the low heating value of the coal, permits each unit of grate surface to deliver only a very low amount of heat, and necessitates additional grate surface.

With equally well proportioned furnaces and similar loads, Chain Grates show an increased combined efficiency (Item 73 A. S. M. E. Code) of 5 per cent over the best hand fired results. This figure is from exhaustive tests made before and after equipping a large hand-fired plant with

Chain Grates. The 5 per cent is necessarily accredited to the uniformity of firing, the evenness of the fuel bed, and the prevention of cold air into the furnace. However, such a comparison is unfair to the stoker, inasmuch as both tests were carefully and skillfully fired, and in Chain Grate firing skill is not so potent a factor as in hand-firing. Due to carelessness or the lack of skill of the fireman, it is safe to say that in the average hand-fired plant there is a possibility of 10 per cent increase in efficiency by the installation of Chain Grates. In addition to this actual thermal saving, there often occurs a reduction in the coal bills, due to the fact that the cost of low grade fuel is much lower than that of the high grades, the variation not always being in direct ratio to the heating value of the coals, but often very much in favor of the lower grades.

Much has been written about the adaptability of the stoker to fluctuating loads. It has been the writer's observation that stokers having adequate draft and properly handled can be made to respond to fluctuating loads and sudden peaks as readily as hand fires, in proof of which the results of a test with a fluctuating load test are submitted.

Plate A is a graphical representation of the hourly horse power developed during a 24 hour economy test, the conditions under which the test was made being that the fluctuating heat, light and power load of the station be carried throughout the test. The height of the water in the gauge glass did



HORSE POWER DEVELOPED, POUNDS OF WATER EVAPORATED PER HR. F. & A. 212° F. ÷ 34.5
800
700
600
500
400
300
200
100
0
5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5
MIDNIGHT
NOON
DIAGRAM SHOWING THE PERFORMANCE OF A CHAIN GRATE WITH A FLUCTUATING LOAD
TOTAL HEATING SURFACE - 5280 □'
" GRATE " 117 □'
PERCENT OF RATING DEVELOPED
MAXIMUM - - - 139
MINIMUM 20
COMBINED EFFICIENCY OF TOTAL RUN 65%

PLATE A

not vary one inch during the entire time, it being kept constant by means of a feed water regulator. The load, varying from 107 H. P. as a minimum to 732 H. P. as a maximum, or from 20 per cent to 139 per cent of the rated capacity of the boilers, was carried on two 264 H. P. B. & W. boilers, each equipped with 58.5 sq. ft. of grate surface. The average combined efficiency (Item 73 A. S. M. E. code) developed was 65%, and during the entire run the variation of the steam pressure was only 18 pounds, and at no time did the safety valves pop.

One of the strongest arguments in favor of stoker installations is the reduction in the labor cost of firing. This reduction occurs in plants in excess of 500 H. P., and increases very rapidly with the size of the installation. With the installation of coal and ash handling machinery, one fireman can give good attention to six units, regulating the furnace conditions and draft, and tending water. Should these units be large, say 600 H. P., the rated boiler horse power controlled by one man would be 3600. With the installation of damper regulators and automatic feed water regulators, one man may be given control of 12 units.

The labor saving, of course, depends entirely on the coal and ash handling machinery with which the installation is equipped, but (other items remaining constant), stoker firing will give a reduction of one man for each 500 H. P. in excess of the first 500 H. P.

Skillful firing by hand is a science, and good firemen are scarce; moreover, large hand-fired plants are in a manner

at the mercy of their firemen. With mechanical stokers this condition ceases to exist, as the number of firemen required is less, and firemen can be broken in in a few hours.

The passing and enforcement of smoke ordinances causes the coal consumers to seek some form of furnace that will fulfill the requirements of smokeless combustion. The Chain Grate satisfied the requirement of "uniform distillation of volatile from coal" better than any other form of mechanical stoker yet designed, and lends itself very readily to the types of setting necessary to fulfill the other requirements.

DESIGNING OF BOILER LAYOUTS AND CHAIN GRATE SETTINGS.

The boiler room arrangement is one of first importance in power station economy. Boiler settings may be designed that will give excellent individual economy, but if the arrangement is such that the fireman cannot give the proper attention to the fires, or such that the boilers cannot be properly cleaned and soot blown from the tubes at regular intervals, the economy of the plant under operative conditions will be low, and the labor cost of operation will be high. Wherever possible the following items should be provided for:

Four foot alley ways between boilers, providing space for removal of clinker and soot.

Twenty foot front space from boiler front to building wall.

Ample head room.

Large and well designed breeching having few turns and no sharp bends.

Light alleys behind boilers, permitting free access to blow-off cocks.

Ample room for ash removal.

Frequently it is impossible to obtain one or more of these items, and as a result some details of operation are neglected with corresponding losses.

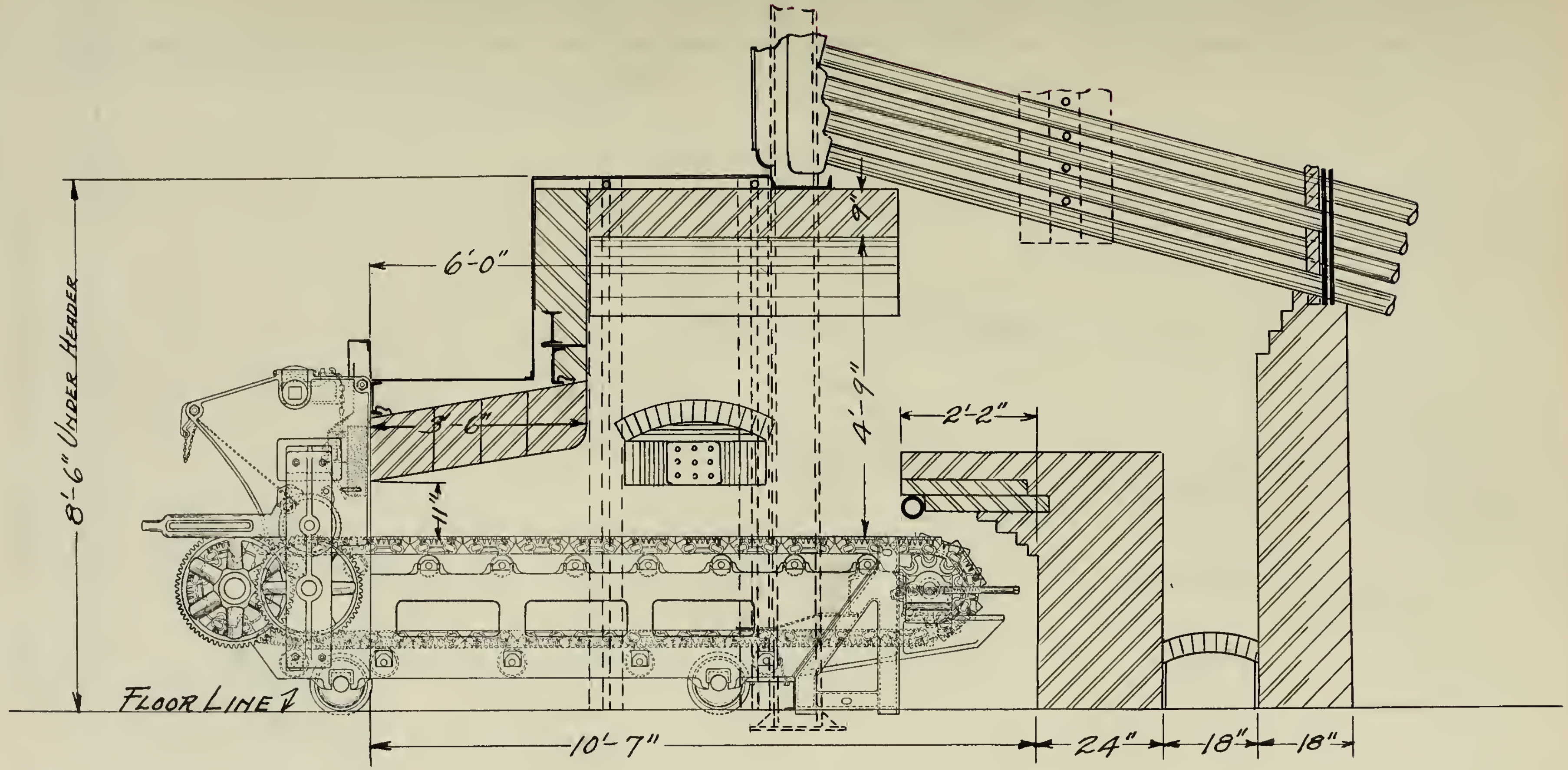
DESIGN OF THE FURNACE.

As Mr. Bement has expressed it, there are three links to the steam generator, viz., the fire grate, the furnace, and the boiler. We have dealt with the fire grate in our discussion of the stoker itself. Combustion, if complete, must occur in a furnace with walls and roof constructed of refractory material and of ample proportion to permit of complete mixing and union of the gases. When such conditions exist no smoke is generated.

The subject of the design of Chain Grate furnaces has been very thoroughly covered in the papers of the Western Society of Mechanical Engineers, hereinbefore mentioned, and the writer will do no more than to indicate a suitable furnace for each type of boiler.

Furnaces in which complete combustion occur when burning Illinois screenings of high volatile content are being obtained under Babcock & Wilcox boilers, having eight feet six inches (Fig. 11) under the front header, and a furnace projection of six feet. With these dimensions it is possible to obtain an arch projecting entirely over the grate surface and having a positive mixing effect produced by the difference in elevation between the ignition and secondary arch. The flames penetrate among the tubes probably three or four feet before the combustion has reached a stage where the chilling effect of the tube is not sufficient to produce smoke, when operated at normal ratings. This setting is

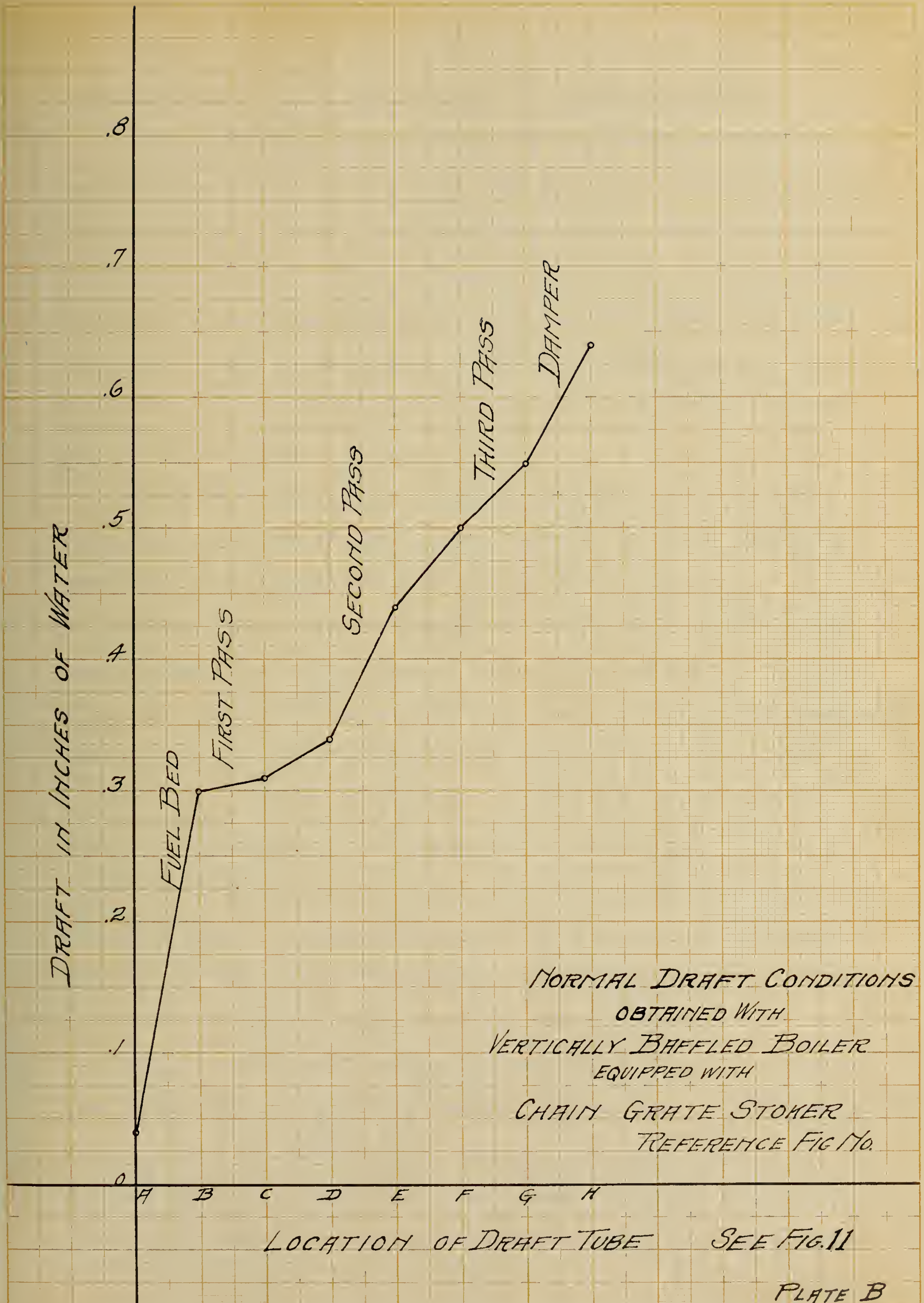
[illegible]



Horizontal Water Tube Boiler ~ Vertical Pass
Equipped With Chain Grate Furnace

Fig 11

Fig. 11



DRAFT IN INCHES OF WATER
.8
.7
.6
.5
.4
.3
.2
.1
0
FUEL BED
FIRST PASS
SECOND PASS
THIRD PASS
DAMPER
NORMAL DRAFT CONDITIONS
OBTAINED WITH
VERTICALLY BAFFLED BOILER
EQUIPPED WITH
CHAIN GRATE STOKER
REFERENCE FIG NO.
A
B
C
D
E
F
G
H
LOCATION OF DRAFT TUBE
SEE FIG. 11

PLATE B

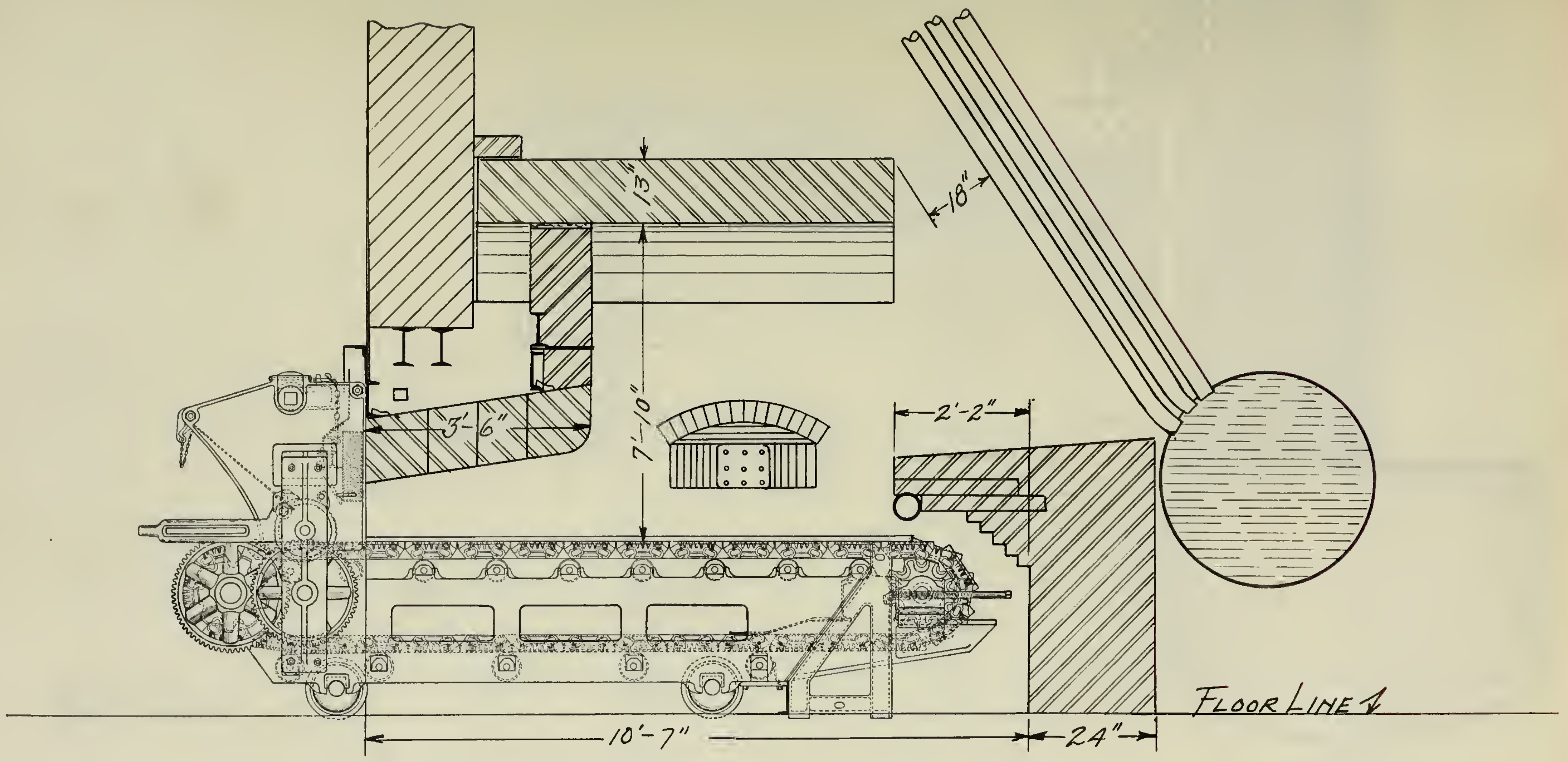
approved by the smoke departments of the large cities.

With a Stirling boiler (Fig. 12) the combined igniting and Stirling arch, equal to the length of active grate surface, provide ample furnace, with excellent mixing conditions at the desired point. Such settings always give complete combustion and smokelessness up to very high ratings. In this case the travel of the gases is along the tubes, and it is probable that the gases are not as much broken up as in the Babcock & Wilcox type.

The Wickes (Fig. 13) and Cahall Vertical Boiler, both have the same type of dutch oven furnace, and give perfect conditions as regards combustion and smokelessness.

The type of boiler provided with tube tile on the lower row of tubes, as in the Heine, Murray Iron or O'Brien Boilers (Fig. 14) naturally extend the incandescent fire brick chamber just that much more, and the arch provided with the stoker need not be as long, therefore, as with the type of boiler having the passage of the gases across the tubes. In this type of setting it is usual for the flame to be completely consumed before the heating surface of the boiler is reached. Because of the strong arch effect, this setting has a stronger ignition than the other types herein mentioned.

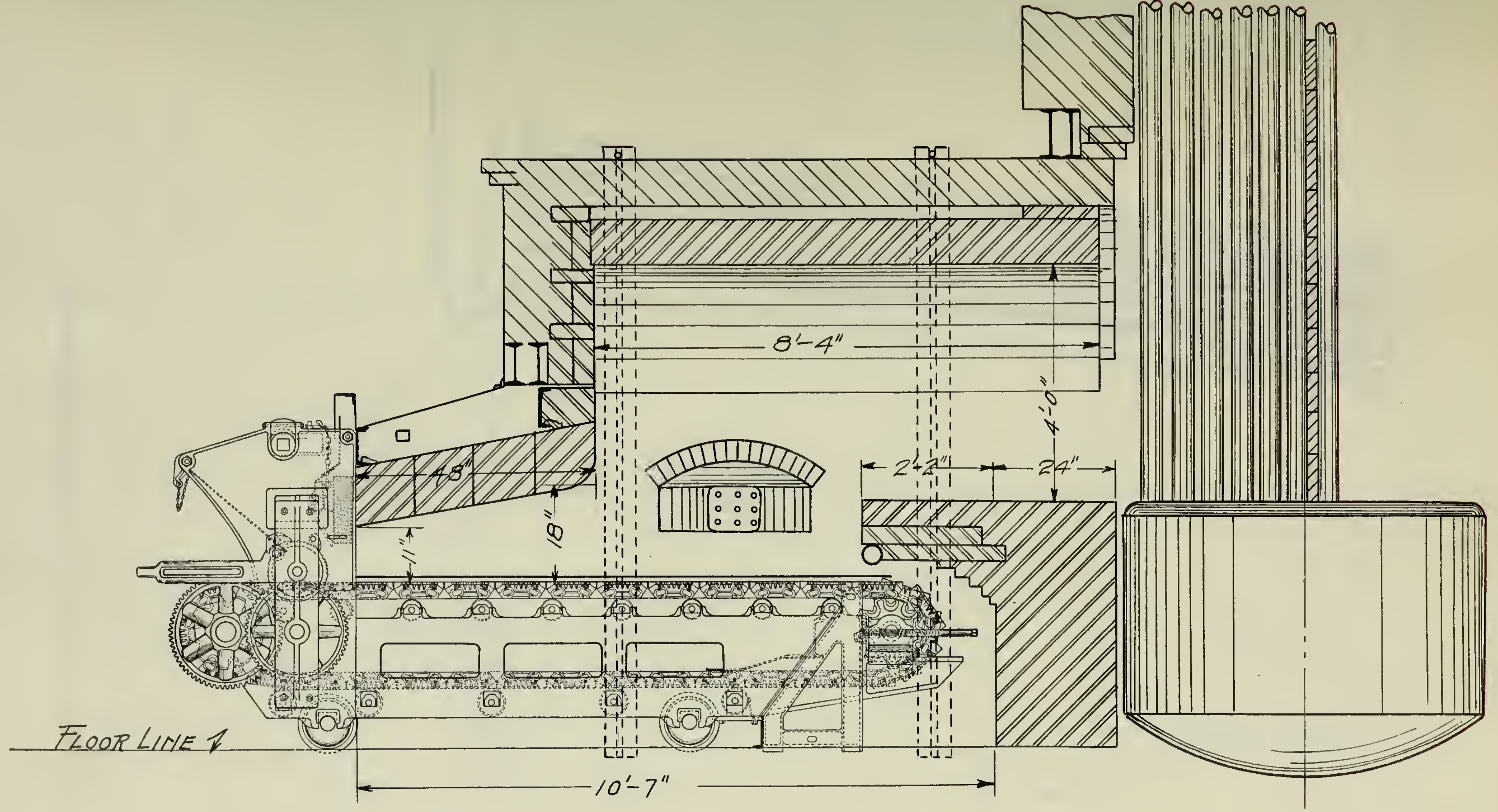
With the Return-Tube type of boiler, such as the Bonson, the Sederholm, or the Scotch Marine boiler, the flame must be entirely extinguished before reaching the fire tubes, as instant extinction occurs at the moment the gases enter the tubes. However, in the ordinary Return-Tube type of boilers,



STIRLING BOILER
EQUIPPED WITH CHAIN GRATE FURNACE

FIG 12

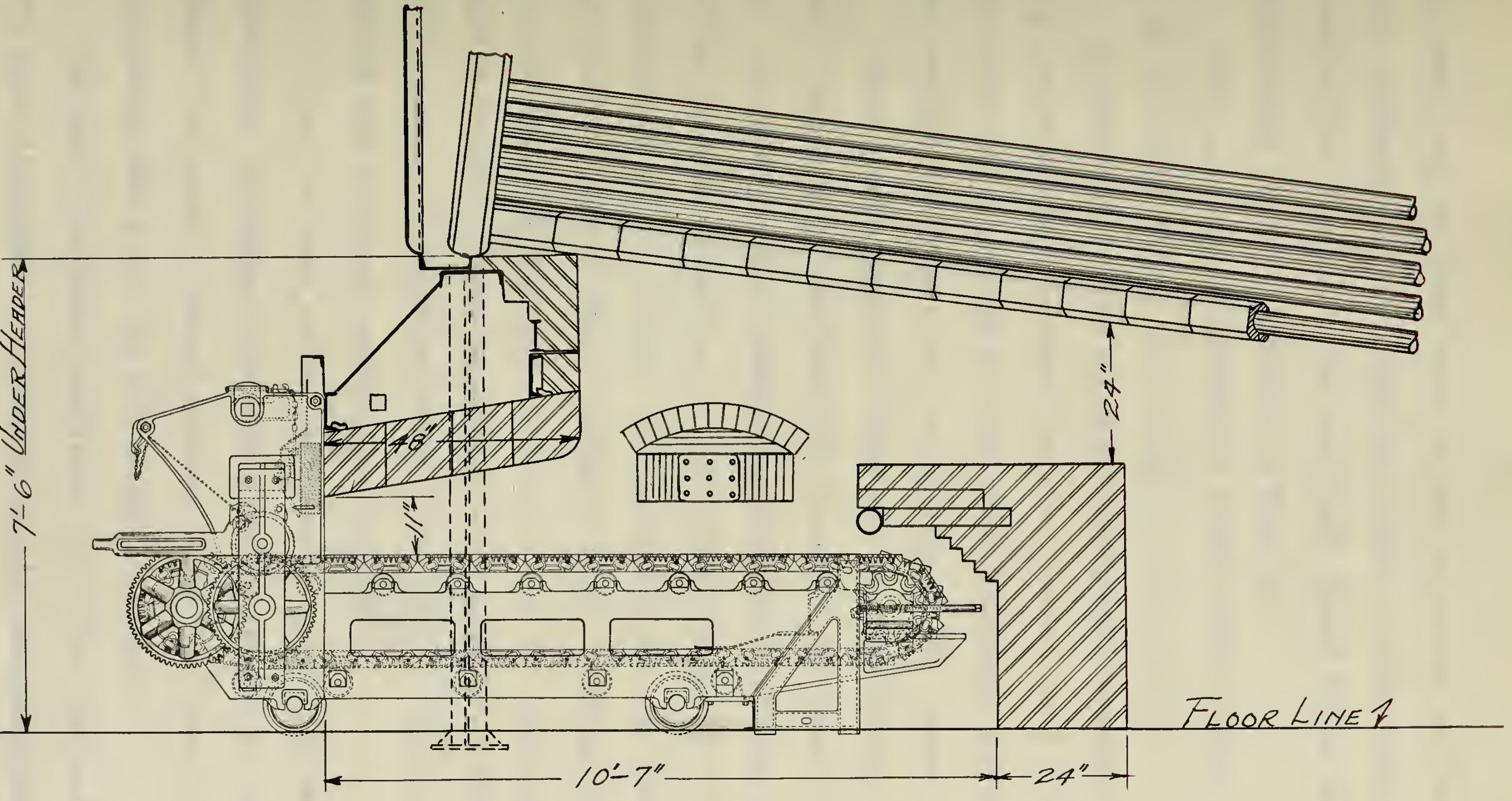
FIG. 12



WICKES VERTICAL BOILER
EQUIPPED WITH CHAIN GRATE FURNACE

FIG. 13

FIG. 13



HORIZONTAL WATER TUBE BOILER WITH HORIZONTAL BAFFLES
EQUIPPED WITH CHAIN GRATE FURNACE

FIG. 14

FIG. 14

the shell may be considered as an extension of the furnace roof, inasmuch as its chilling effect is not sufficient to extinguish the flames. An excellent Chain Grate setting under a Return-Tube boiler is shown in Fig. 15.

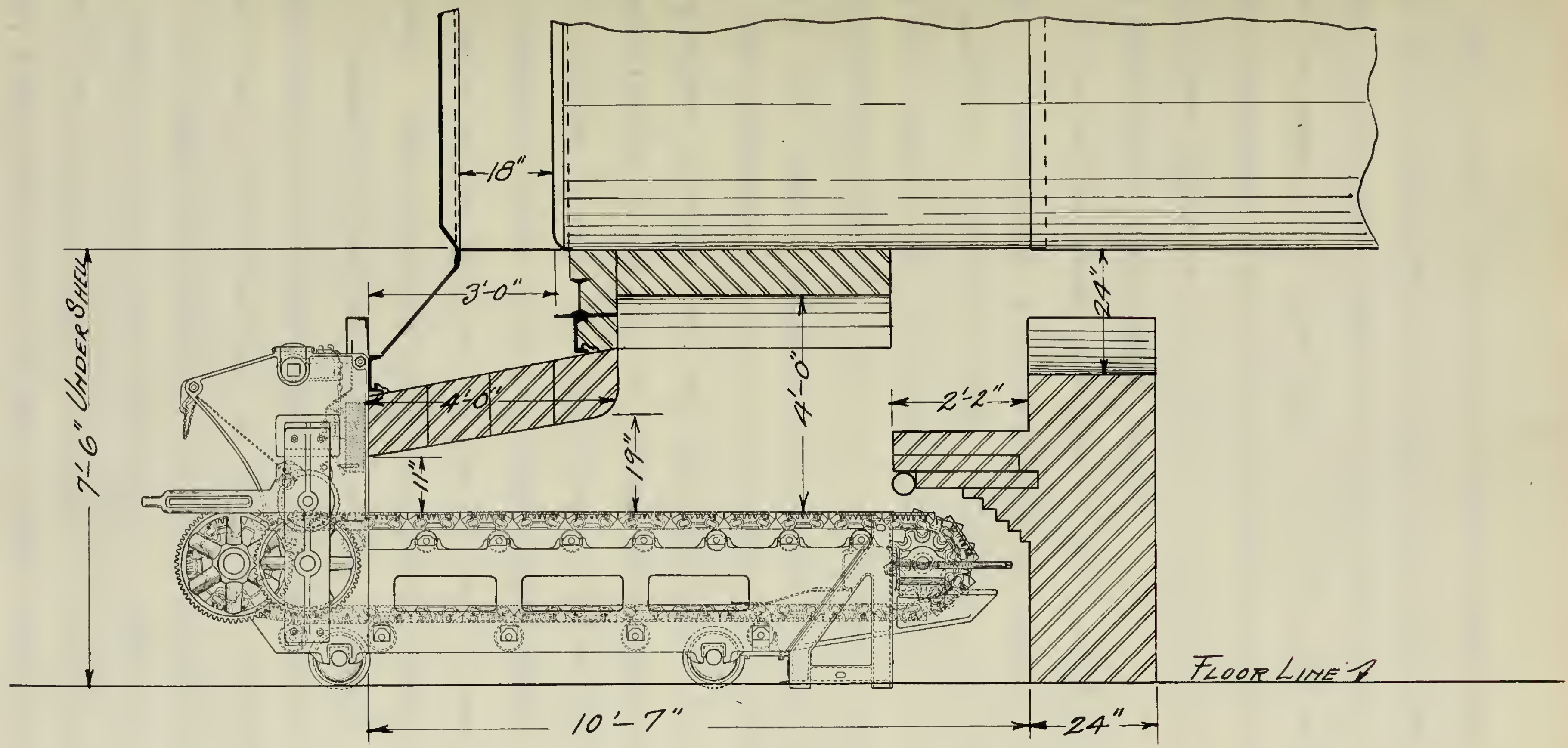
This setting is smokeless within the Chicago ordinance up to 30 per cent above the rating of the boiler.

In general it may be said of furnace construction, that to produce perfect combustion the furnace roof should extend over the entire length of the grate surface, and be of sufficient height to permit of the mixing of the gases.

Chain grate practice does not require as much incandescent brickwork in conjunction therewith as hand-fired practice, inasmuch as the gradual introduction of the fuel results in the gradual evolution of the volatile combustible, and the termination of the flames at approximately the same point at all times. The sudden introduction of several shovelsfull of coal into the furnace in the period of a few seconds, results in the sudden evolution of a body of volatile gas which cannot be consumed within the time of its passage through the ordinary combustion chamber.

It may be here noted that the long-flaming Western coals, especially if washed, require greater length of combustion chamber to produce smokelessness, than the short-flaming semi-bituminous coals of the Pittsburgh district.

The most desirable settings with the standard boilers have been discussed. However, it is comparatively seldom that it is possible to construct settings of such proportions.



HORIZONTAL RETURN TUBULAR BOILER
EQUIPPED WITH CHAIN GRATE FURNACE

FIG. 15

FIG. 15

Many Chain grate installations replace hand-fired grates, or other form of apparatus not requiring as much head room or front room, and as a result the Chain grate has to be crowded in at the expense of economical combustion and smokelessness. It also sometimes occurs that new buildings are designed with insufficient space for the design of smokeless furnaces, and some make-shift arrangements result.

It is not uncommon practice to make capacity the chief item. In such cases grate surfaces of unusual dimensions are specified, and boiler horse powers are obtained oftener from five square feet of heating surface than from ten. Chain Grate settings having a ratio to the heating surface of more than 1 to 45 may be considered as designed for capacity.

The maintenance cost of the metal parts of the Chain Grate Stoker is very low, for the reason that the grates are intermittently in and out of the furnace, thus providing them with a chance to cool off, together with the fact that the best designed stoker chains provide thirty square feet of heat radiating surface to one square foot of heat absorbing surface. The operating mechanism is not exposed to the heat, and is usually of ample proportions for strength. The maintenance cost of the metal parts of Chain Grates is usually below 3 per cent of the cost of the entire investment. The cost of furnace maintenance is an item variable with the type and design, as with local conditions. Table No. 1 was compiled from data furnished by a plant of 14,800 boiler horse power, being equipped with twenty seven Chain Grate Stokers.

The maintenance conditions may be considered very severe, inasmuch as sixteen of the furnaces are of the dutch-oven design, having arches thirteen feet long. The item of greatest interest is perhaps the total annual maintenance of stokers and furnaces per 100 horse power, which is $61.75.

Table No. 1

ANNUAL MAINTENANCE EXPENSE OF CHAIN GRATES

Unit	Annual Material Cost			Annual Labor Cost	Total Annual Cost of Stokers & Furnaces
	Arches	Stokers	Total material		
Total Installation 14800 H. P.	$5727.95	$1377.00	$7104.95	$2034.50	$9138.45
100 H. P.	38.70	9.30	48.00	13.75	61.75
1 H. P.	.3870	.0930	.4800	.1375	.6175
1 front foot of grate width	19.00	4.57	23.57	7.00	30.57
1 square foot of grate area	1.975	.475	2.45	.70	3.15

NOTE: Installation under consideration consists of

20 - 600 H. P. boilers,

7 - 400 H. P. boilers,

16 of which have 13 ft. long arches,

11 of which have 5 ft. long arches.

CONSTRUCTION

Furnace walls to withstand the heat must have a lining of at least nine inches of No. 1 fire brick. These should be laid in fire clay with great care, the method being to dip the bricks in fire clay "grout", then rub and tap them into place, bringing the brick tightly against each other, the clay merely filling the voids. Fire clay of such consistency as to permit the use of a trowel should not be permitted in furnace work, and particularly in arch work. Fire clay has practically no cementing power, and has the additional defect of shrinking. To add to the former it is good practice to slack in 1¼ per cent of lime with the fire clay. This will assist in forming a flux or clinker that will take a grip on the brickwork. The addition of about 20 per cent of pulverized fire brick is sometimes practiced to overcome the shrinking of the clay. Washing the surface of all fire-brick work with a solution of fire clay and salt (a double handfull of salt to a bucket of "grout"), will cause an excellent glaze to form at the first firing, and materially increase the life of the brickwork.

Arch construction requires special care, it being imperative that the tile are laid absolutely brick to brick and laid dry. When the tile are all set in place the whole arch is thoroughly grouted with a thin solution of fire clay poured in from above.

All suspended arches have metal supports, and it is very essential that a proper ventilation scheme be installed for the

purpose of keeping these supports cool. This is done by causing an air current to pass over the top of the arch, the current being created by the furnace draft, and ducts being left through the outside wall and curtain wall of the furnace to permit of this system.

The construction of the bridgewall overhang is not so difficult, as it is customary to have special shaped tile, and thus avoid excessive corbeling out, and these tile rest on the waterback, making a strong and simple design.

The red or common brick forming the outside of the furnace wall should be well burned and uniform in size. The mortar in which these are laid should be composed of one part of lime to three parts of clean,sharp sand. The longer the lime has been slacked the better. Every fifth course should be a header, and extreme care should be exercised in filling all interstices in order to prevent the infiltration of air, which reduces the draft and lowers the boiler economy.

The most advantageous manner of erecting a Chain Grate installation,is to set the stoker rails at the time of laying the boiler foundations; then erect the boiler to the point at which it is ready for brickwork. At this time the stoker should be erected and set in its correct position. The brickwork of the furnace can then be built very close and tight to the stoker, cutting off all undue air leaks and preventing the possible mistakes of too wide or too narrow furnace. This procedure also permits the brick masons to utilize the grate surface on which to construct the centers for the

igniting arch and boiler arch, if such be used.

The erection of the machine itself is usually a simple matter, as most firms erect all machines in the shop, and number the parts before shipping, but the engineer in charge of erection must give close attention to the brickwork, watching all dimensions and the manner of laying all brick.

CHIMNEY DRAFT

Chimney draft is the difference in pressure causing air to pass through the fuel bed, and the products of combustion to pass through the various passes of the boiler. This difference in pressure is caused by the difference in weight between the column of heated air inside the chimney and the cold external air. The difference in potential caused by the difference in weight of the column of air inside the chimney and the column of air outside the chimney causes a continuous difference in pressure upon the body of gases composed of the air entering the furnace under the grate and the products of combustion leaving the boiler setting. This continuous difference in pressure imparts motion or velocity to the gases.

Draft pressure created by a stack under any conditions may be calculated from the formula:-

$$D = .52\,H \times P\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

in which:-

D = draft pressure produced measured in inches of water from atmospheric pressure.

H = height of top of stack above the grate surface in feet.

P = atmospheric pressure in pounds per square inch.

T_1 = atmospheric temperature absolute.

T_2 = absolute temperature of stack gases.

The factor .52 takes into account the pressure per square inch of water, and the decimal point.

This formula does not take into account the density of the flue gases, it being assumed to be practically equivalent to that of air.

This formula gives the theoretical draft pressure. On account of the friction of the gases against the sides of the stack, the actual available stack pressure is only about 80 per cent of the theoretical value.

Extremely porous chimneys or connections thereto decrease the draft pressure of a given stack but it is an unusual case in which the actual value varies more than 5 per cent from the calculated value.

In the discussion thus far only chimneys have been mentioned. The case is unaltered if for the chimney is substituted the induced draft fan, or any of the forced draft systems. In each case the same fundamental condition exists, a continuous difference in pressure driving the gases through the boiler setting.

INDUCED DRAFT

The installation of induced draft sets in connection with Chain Grates is gaining much favor, an increasing per cent of such installations being built each year. The induced draft system insures ample draft for any conditions of design or operation that may arise, and makes a very flexible system, quickly responsive to load fluctuations. Care must, however, be taken with such systems, as it is easily possible to destroy a furnace in a short time by accumulating a large amount of ignited fuel therein, and then driving a large volume of air therethrough. The author has seen the brickwork of furnaces ruined in a short period in this manner. Because of this condition, and of increased number of variables, more intelligent operation of such systems is required than for installations in which the chimney affords the difference in pressure.

FORCED DRAFT

Forced draft has been attempted in a few cases in connection with Chain Grates, the system being to house over the front of the chain and force air thereunder. The system is operative, but the danger is ever eminent of creating a plenum in the furnace by admitting too much air. For this reason the forced draft system has gained little favor, giving way to the induced system. In case of forced draft installations it is absolutely essential that the air be introduced at a point below the lower lead of the stoker chain, thus

causing it to pass therethrough, on its way to the furnace. Otherwise there is no air circulation through the chain, with the result of the chain becoming excessively hot and rapidly deteriorating.

From the chimney to the ash pit the difference in pressure that is universally known as draft is caused by the difference in the velocity of the gases, which is in turn affected by the resistance offered to their passage, whether such resistance be useful such as that offered by a bank of boiler tubes, or non-useful such as caused by a deposit of soot, a sharp turn in a breeching, or a restricted area.

It frequently occurs that breechings are so designed that, because of restricted areas or tortuous passages, the amount of air that can be forced through a given fuel bed is greatly deficient of the proper amount for a furnace and boiler of given proportions.

In the design of the breeching the following general rules should be borne in mind.

1. The retarding effect of a square flue is 12 per cent greater than a circular one of the same area.

2. Abrupt turns should be avoided where possible, use being made of long easy sweeps.

3. With circular steel flues of the same size as the stack, or reduced proportionately to the volume of gases, a convenient rule to follow is to allow one inch draft loss per each hundred feet length of flue, and five hundredths inch for each right angle turn. For square or rectangular brick

flues these should be doubled.

Figure 16 represents a steel breeching of very good design recently investigated by the writer. It was constructed of No. 6 steel plate riveted closely and tightly connected to the boilers. The proportions were ample, and the workmanship was excellent. The decrease in velocity of the gases through this breeching was very moderate, being from .85" to .65" in traveling a distance of forty feet and making three right angle turns.

An explosion of gas from a gas-fired boiler gave rise to numerous leaks in this breeching, making it on a par in that respect to one poorly constructed or in a bad state of repair. The effect was .09" of draft at the boiler damper, or 13.9 per cent loss in effectiveness.

TABLE NO. II.

Referring to Fig. 16					
Location of section considered	Area sq.ft.	Ratio to grate surface	Draft reading obtained before explosion in. of H_2O	Draft reading obtained after explosion in. of H_2O	Per cent loss due to leaks.
B	40	1 to 6.7	.68		
C	40	1 to 6.7	.68		
D	37.5	1 to 5.5	.67	.65	
E	27.5	1 to 4.8	.65	.56	13.9
F	20.0	1 to 3.3			
Area of chimney 28 square feet					
Ratio to grate surface 1 to 9.5					
Draft pressure in chimney base .85".					

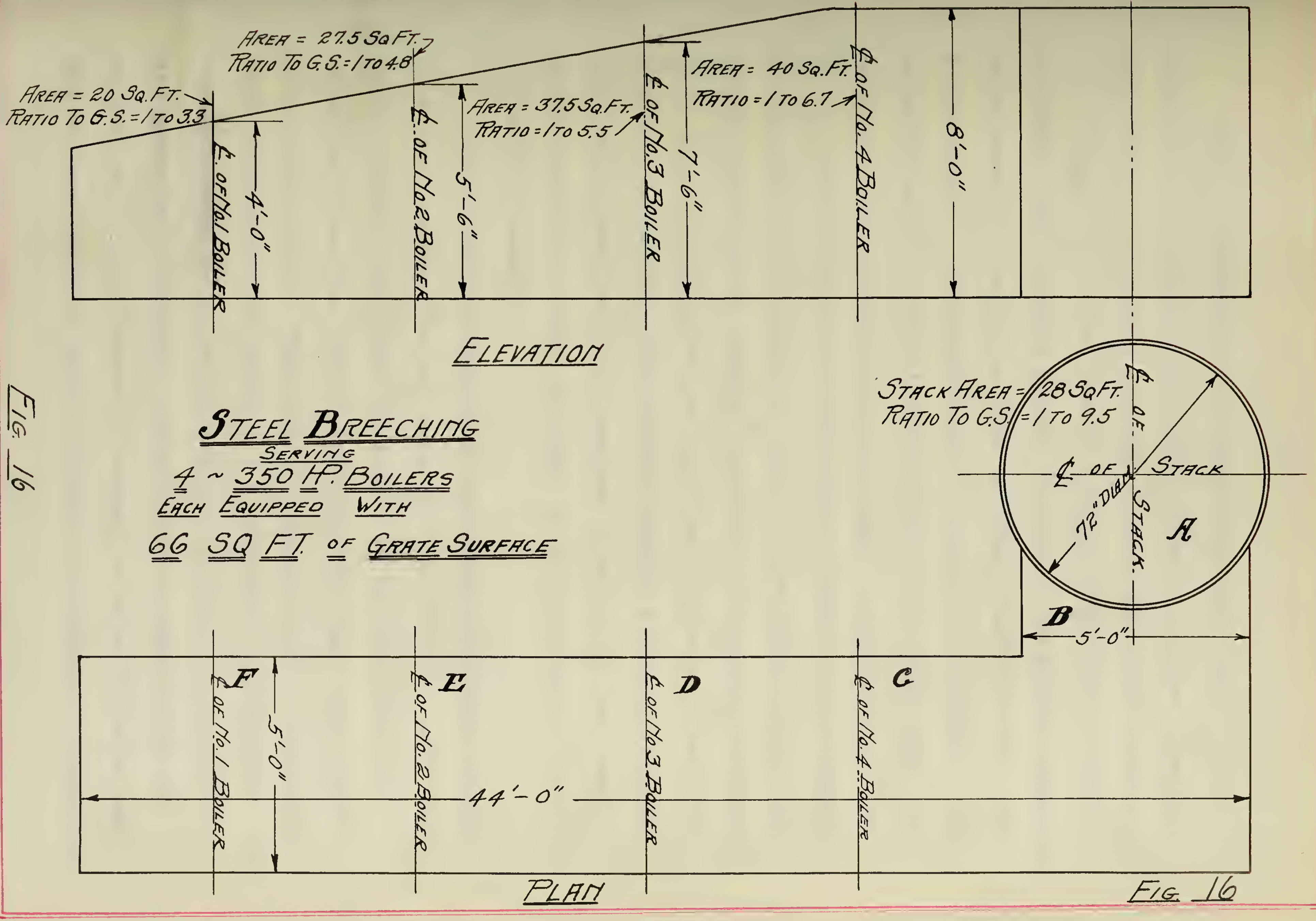

AREA = 20 SQ. FT.
RATIO TO G.S. = 1 TO 3.3
AREA = 27.5 SQ. FT.
RATIO TO G.S. = 1 TO 4.8
AREA = 37.5 SQ. FT.
RATIO = 1 TO 5.5
AREA = 40 SQ. FT.
RATIO = 1 TO 6.7
℄ OF NO. 1 BOILER
℄ OF NO. 2 BOILER
℄ OF NO. 3 BOILER
℄ OF NO. 4 BOILER
4'-0"
5'-6"
7'-6"
8'-0"
ELEVATION
STACK AREA = 28 SQ. FT.
RATIO TO G.S. = 1 TO 9.5
℄ OF STACK
℄ OF STACK.
72" DIAM.
A
B
5'-0"
STEEL BREECHING
SERVING
4 ~ 350 H.P. BOILERS
EACH EQUIPPED WITH
66 SQ FT. OF GRATE SURFACE
F
E
D
C
℄ OF NO. 1 BOILER
℄ OF NO. 2 BOILER
℄ OF NO. 3 BOILER
℄ OF NO. 4 BOILER
5'-0"
44'-0"
PLAN

FIG. 16

Having considered the chimney and the effects on the velocity of the gases caused by variously designed breechings, we arrive at the boiler setting. Restricted areas in the boiler setting proper give rise to a large proportion of "stoker troubles", and for this reason the writer has made a considerable investigation of the best existing conditions from combined capacity and maintenance of furnaces and stokers. Disregarding any one of these items would, of course, alter the problem, but in practice the three must go together and the object of the study of the furnaces and settings,and conditions pertaining thereto has been to investigate conditions highly desirable and readily obtainable in commercial plants. With this in mind the writer has investigated such settings as give high economy and furnace capacity together with low maintenance cost,and has attempted to set forth the conditions requisite in such settings, to assist others in obtaining similar results.

One of the most indicative conditions regarding economy at a given rating, furnace capacity obtainable or maintenance costs of boiler settings and grates is the difference in potential along the line of travel of the gases from the ash pit to the uptake. The flow is from the point of high potential, the ash pit, to that of low potential, the chimney, and the difference of potential between any point in the path of the gases and atmospheric pressure may be measured in the ability of such difference to sustain a column of water and may be considered as the net pressure forcing air through the

interstices of the brickwork constituting the boiler setting.

The friction due to the restricted passages through which the gases must pass in the various types of boilers in common use causes a draft obtainable in the furnace and available for forcing air through the fuel bed of much less magnitude than that obtainable at the boiler damper, and for any given difference in potential between the ash pit and the uptake there is a certain "fundamental furnace draft" dependent thereon. Should the resistance offered to the passage of air through the fuel bed be increased either by increasing the thickness of the fuel bed or otherwise, the effect would be that insufficient air would be admitted for complete combustion of the fuel, resulting in dull fires and excess coke in the ash.

With the conditions obtaining as hereinafter set forth, this furnace condition is very closely obtained with a six inch fuel bed of $\frac{3}{4}$-in. washed pea coal. It is with such a furnace condition, the boiler damper being wide open and the grate completely covered, (which are standard, highly economical operating conditions) that all the following investigations of the difference in potential due to decrease in velocity or other causes, were made.

Figures 17, 18, 19, 20, 21 and 22 are diagrams of the various common types of boilers, the letters thereon indicating the points at which investigation was made. For convenience of study the draft readings obtained have been shown diagramatically on Plates B, C, D, E, F and G referring in

order to the figures above mentioned. Vertical distances on these diagrams represent draft pressures, and points on the horizontal axis refer to the points of investigation on the boiler diagrams. All values herewith submitted are averages obtained from the investigation of a large number of settings, and the conditions set forth have been repeatedly obtained in new design with the same desired results.

Plate B represents the desirable condition sought for in a vertically baffled boiler of the Babcock & Wilcox type, a diagram of which is shown in Figure 17. It will be noted that the draft variation is very uniform throughout the boiler, there being no excessive loss at any section.

Frequently settings will be found in which the draft conditions vary in a very marked degree from the curve of ideal conditions. Such a case is shown on Plate H. The lower curve (dotted) represents the conditions as found in a certain setting. The draft was low and the boilers would not make capacity. A series of readings at once revealed an excessive drop between the points G and H, or through the damper. The area was measured at the earliest convenience and found to be only one-twelfth of the grate area. This was increased to one-fifth of the grate area, which change affected the draft to the extent shown on the upper curve of Plate H. The alteration of three boilers in this manner effected an economy of 20% in the plant, the saving being due to:-

1. Completely burning the coal, whereas formerly the

ash contained 40 per cent of combustible matter.

2. Increased capacity of the boilers, permitting the plant load to be carried with two boilers, whereas three had formerly been used. This permitted the boilers to be operated at a more economic rating and saved the stand-by losses of a third setting.

Plate C, with reference to the diagram shown in Figure 18, shows the normal draft curve of a horizontally baffled boiler of the type of the Heine, O'Brien, Murray Iron or Erie City. The most severe losses exist at the section between the drums (F - G) and at the front of the upper baffle (E - F). If throttled to the extent of lowering the furnace draft too much, these sections may be relieved as was done in case shown on Plate J, in which the furnace draft was increased from .11 inch to .22 inch, and the capacity and economy at rating materially improved.

The conditions existing in Stirling boilers are shown in Plate D, with reference to Figure 19, the greatest loss being at the third pass E. F.

Plate E shows the condition existing throughout the return tubular setting, Figure 20.

Plate F, and reference Figure 21, represent the draft conditions of the Cahall vertical boiler. It will be noted that there is a restriction to the passage of the gases at the point at which they leave the boiler. This type boiler is so designed. It being a one-pass boiler, is throttled at this section in order to reduce the temperature of the escap-

ing gases. The total pressure drop from the damper to the furnace with this type of boiler is not excessive.

In the Wickes setting, Plate G, Figure 22, the conditions are similar to those existing in the Cahall, the restricted area in this case being the damper opening.

RATIOS

In order to obtain the most satisfactory conditions throughout any boiler setting, it is necessary to obtain certain definite proportions and areas in the various passes. Fundamentally these ratios are based on their ability to accommodate without restriction the volume of gases evolved from the combustion. It has been determined that the flow of gases through areas such as boiler passes is unrestricted so long as the velocity of the gases does not exceed forty feet per second. Basing our calculations on this and on a maximum rate of fuel consumption of thirty pounds per square foot of grate surface per hour, the following ratings are obtained:-

TABLE No. III.

Location of Section	Temperature of Gases °F.	Air Furnished per Lb. of Dry Coal Lbs.	Volumn of Air Passing Section per Lb. of Dry Coal Cu. Ft.	Volumn of Air Passing Section per 30 Lbs. of Dry Coal Cu. Ft.	Area of Section to Permit Air Velocity of 40 Ft. per Sec. Sq Ft.	Ratio of Area of Section to Grate Surface 1 to ?
Over Bridge Wall	2500	18	1485	43740	.303	3
Second Pass	1000	18	693	20790	.14	7
Damper	550	18	478	14340	.1	10

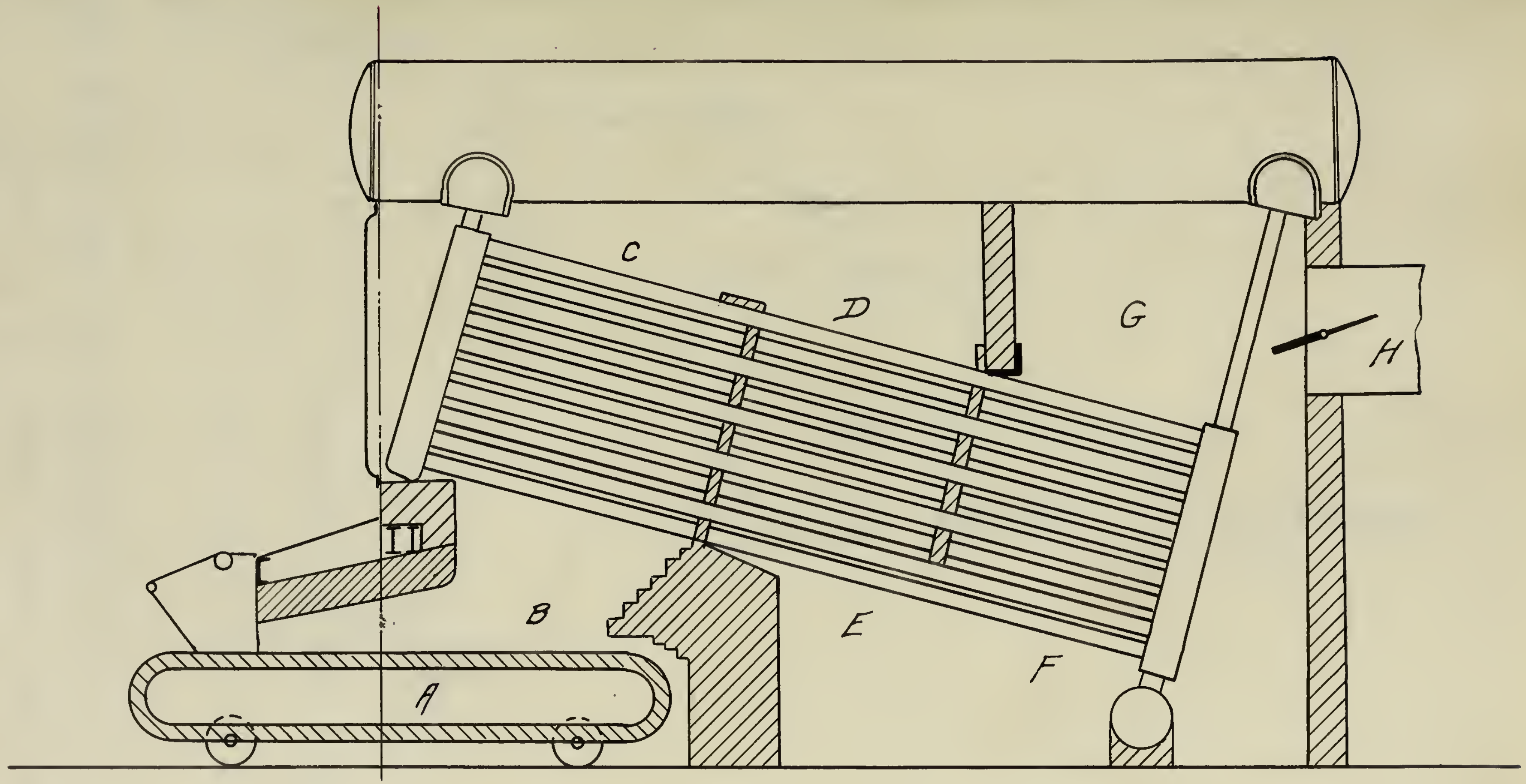
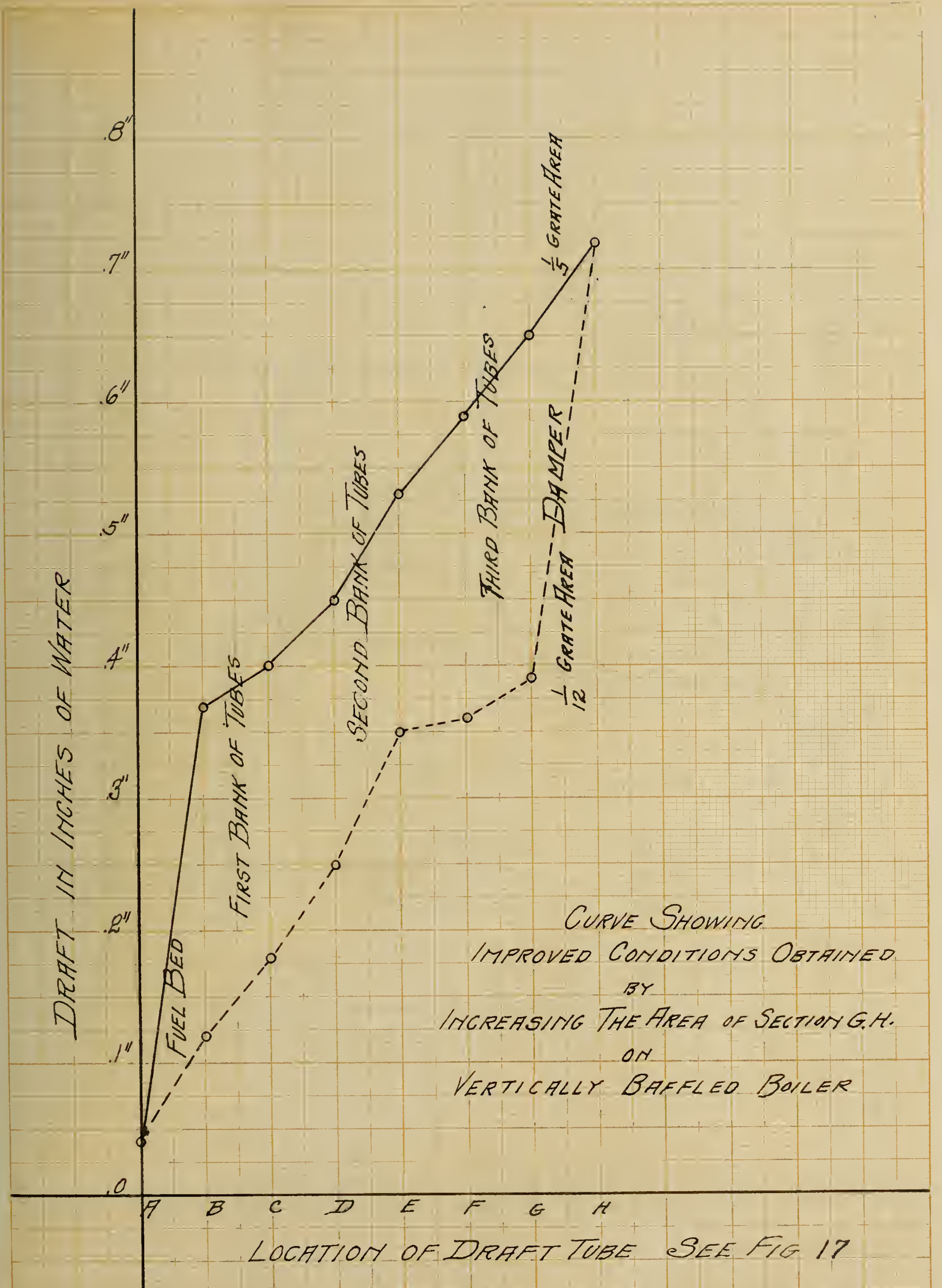


DIAGRAM OF VERTICAL PASS BOILER
FIG. 17


.0
.1"
.2"
.3"
.4"
.5"
.6"
.7"
.8"
DRAFT IN INCHES OF WATER
FUEL BED
FIRST BANK OF TUBES
SECOND BANK OF TUBES
THIRD BANK OF TUBES
DAMPER
1/5 GRATE AREA
1/12 GRATE AREA
A
B
C
D
E
F
G
H
LOCATION OF DRAFT TUBE SEE FIG 17
CURVE SHOWING
IMPROVED CONDITIONS OBTAINED
BY
INCREASING THE AREA OF SECTION G.H.
ON
VERTICALLY BAFFLED BOILER
PLATE H

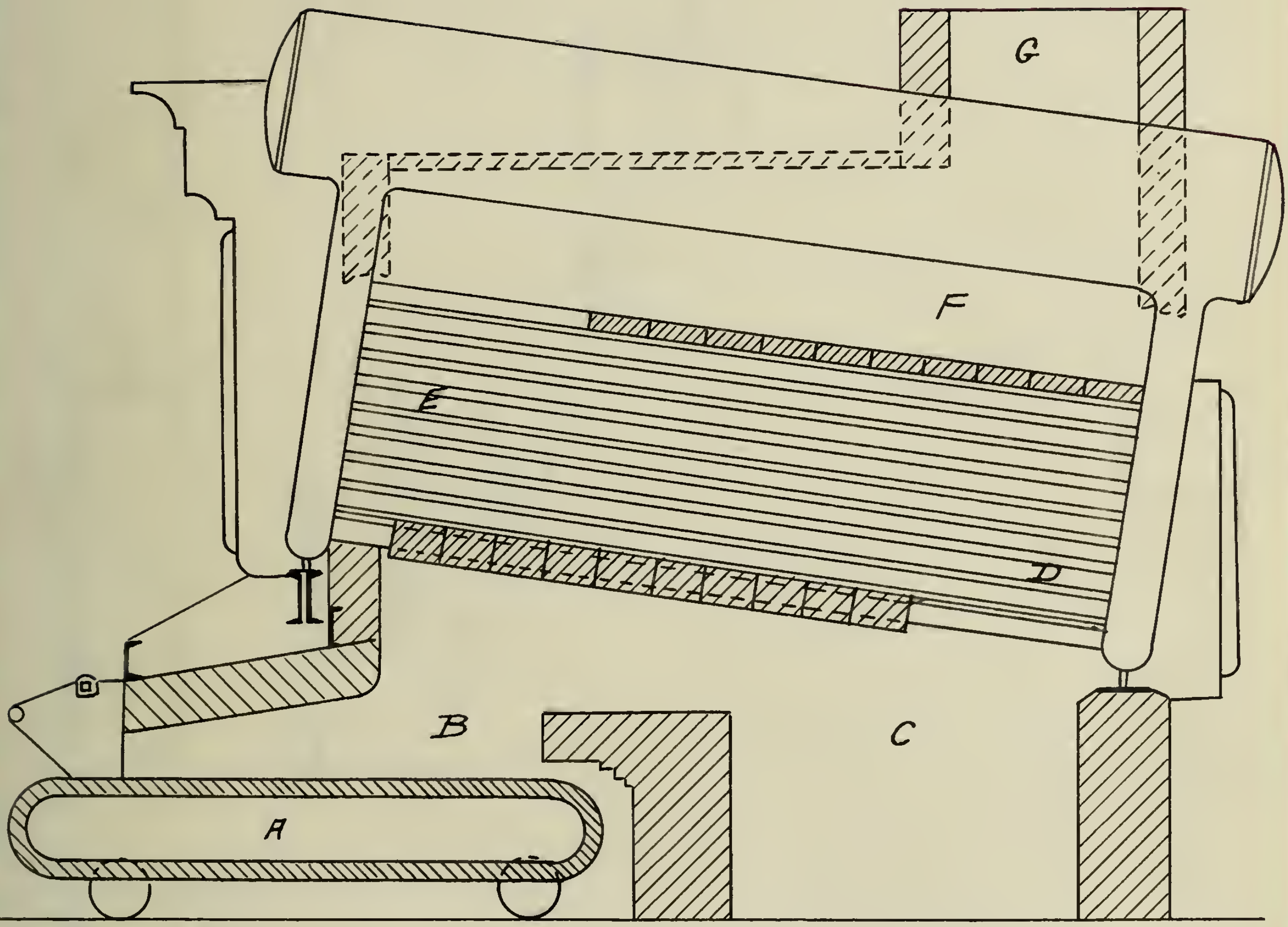


DIAGRAM OF HORIZONTAL PASS BOILER

FIG. 18

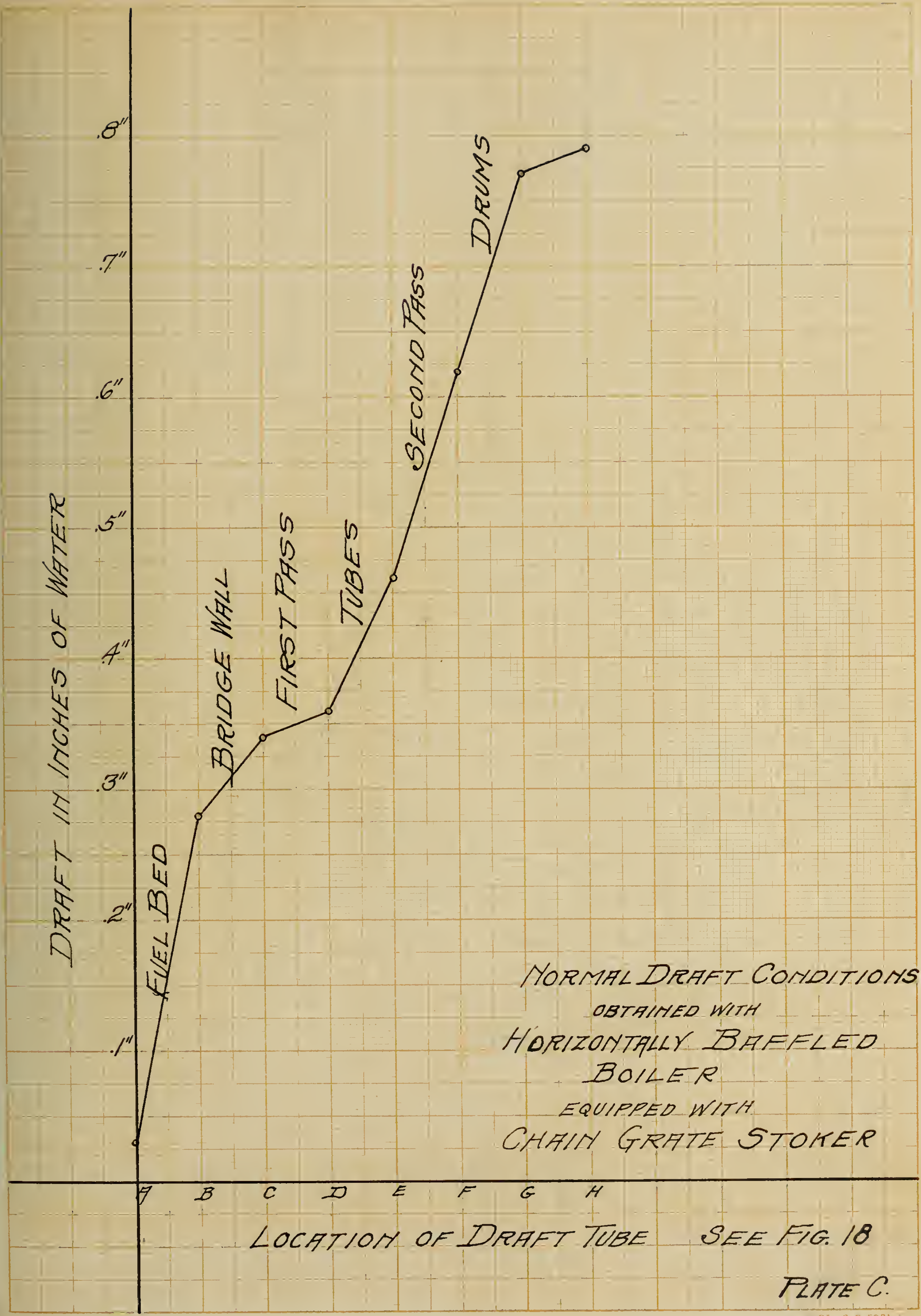
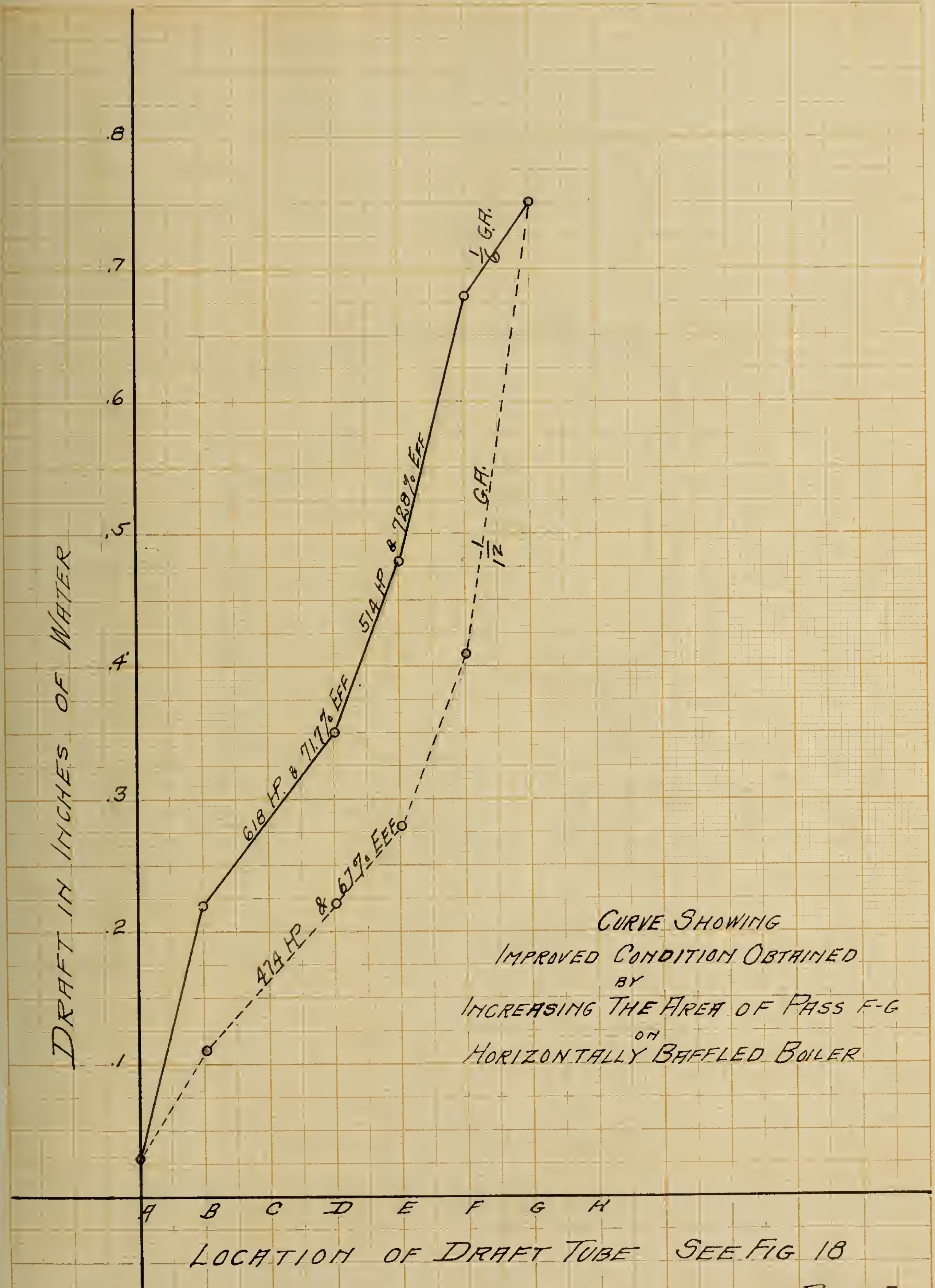

.8"
.7"
.6"
.5"
.4"
.3"
.2"
.1"
DRAFT IN INCHES OF WATER
FUEL BED
BRIDGE WALL
FIRST PASS
TUBES
SECOND PASS
DRUMS
NORMAL DRAFT CONDITIONS
OBTAINED WITH
HORIZONTALLY BAFFLED
BOILER
EQUIPPED WITH
CHAIN GRATE STOKER
A B C D E F G H
LOCATION OF DRAFT TUBE SEE FIG. 18

PLATE C.



.8
.7
.6
.5
.4
.3
.2
.1
DRAFT IN INCHES OF WATER
1/12 G.A.
1/12 G.A.
514 HP. & 72.8% EFF.
618 HP. & 71.7% EFF.
474 HP. & 67% EFF.
CURVE SHOWING
IMPROVED CONDITION OBTAINED
BY
INCREASING THE AREA OF PASS F-G
ON
HORIZONTALLY BAFFLED BOILER
A B C D E F G H
LOCATION OF DRAFT TUBE SEE FIG 18

PLATE J

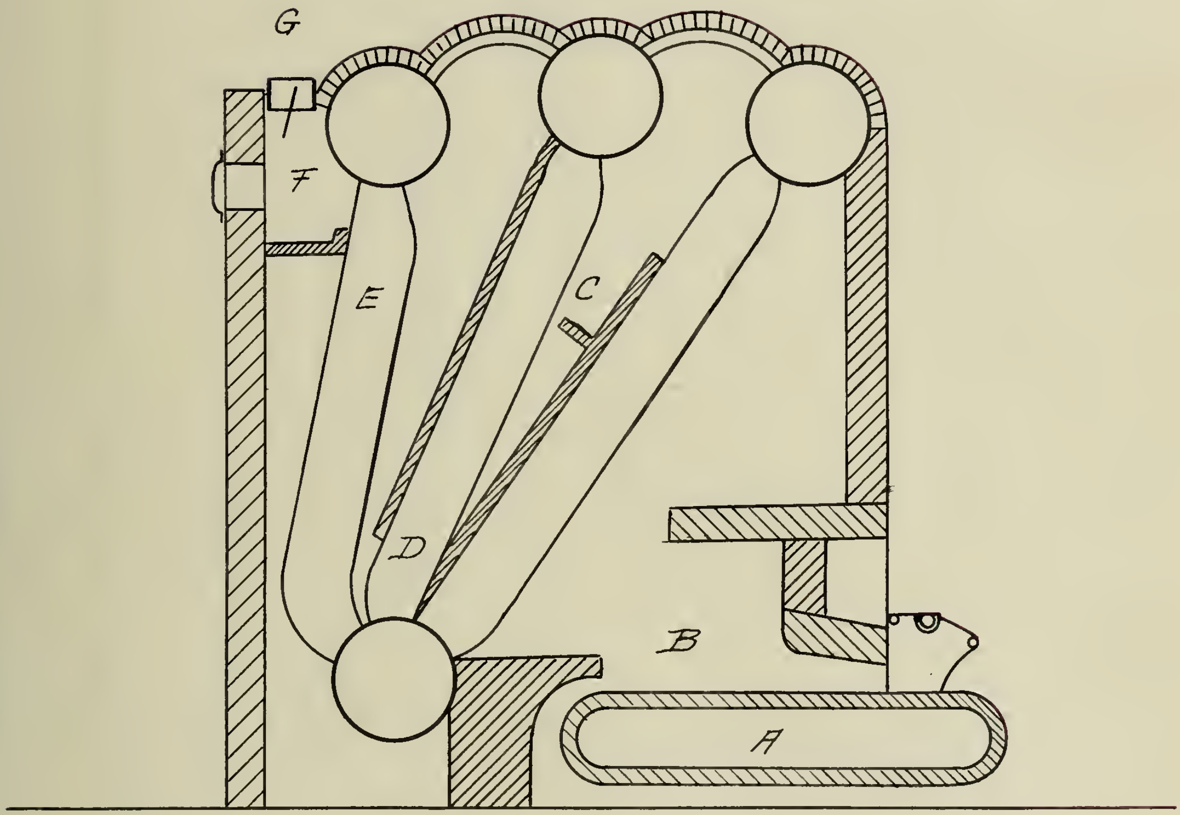
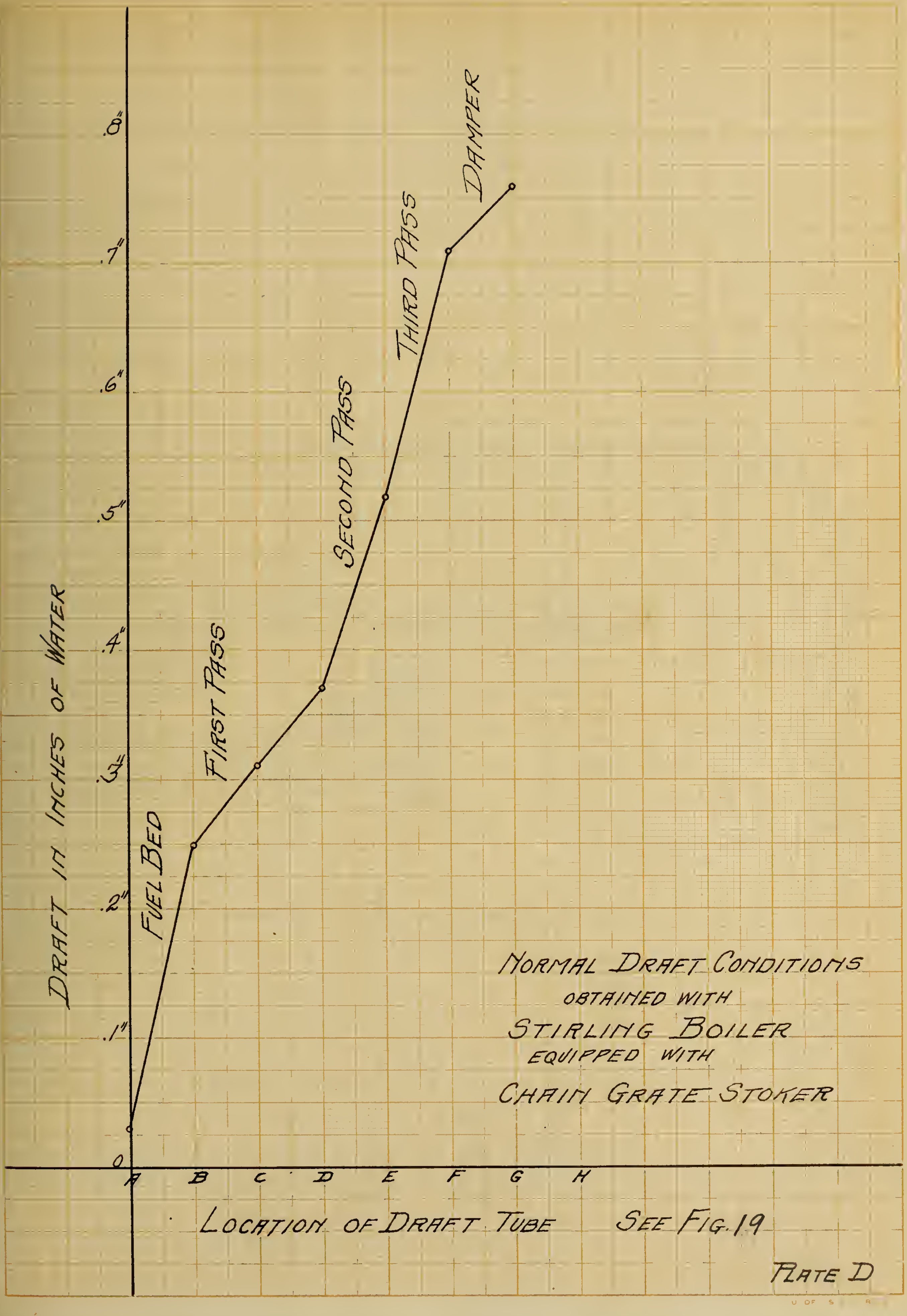


DIAGRAM OF STIRLING BOILER
FIG. 19



.8"
.7"
.6"
.5"
.4"
.3"
.2"
.1"
0
DRAFT IN INCHES OF WATER
FUEL BED
FIRST PASS
SECOND PASS
THIRD PASS
DAMPER
A
B
C
D
E
F
G
H
NORMAL DRAFT CONDITIONS
OBTAINED WITH
STIRLING BOILER
EQUIPPED WITH
CHAIN GRATE STOKER
LOCATION OF DRAFT TUBE
SEE FIG. 19
RATE D

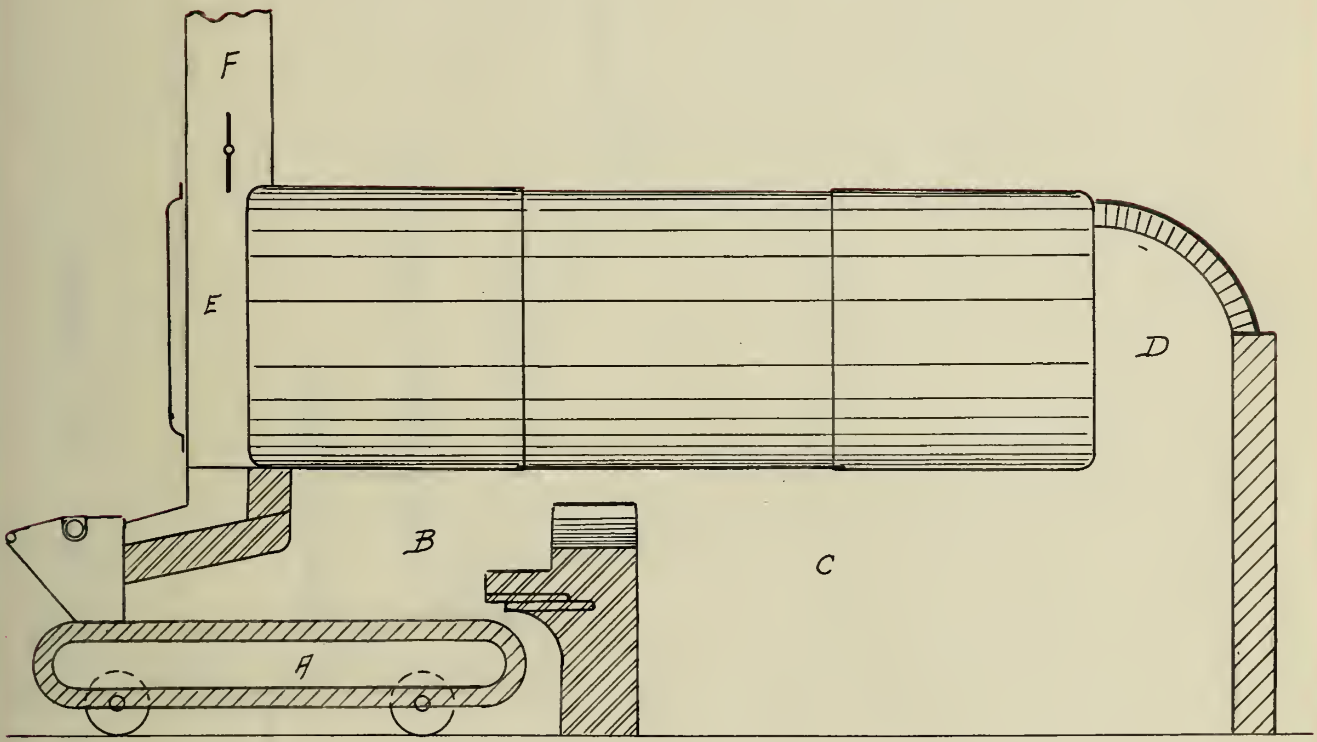
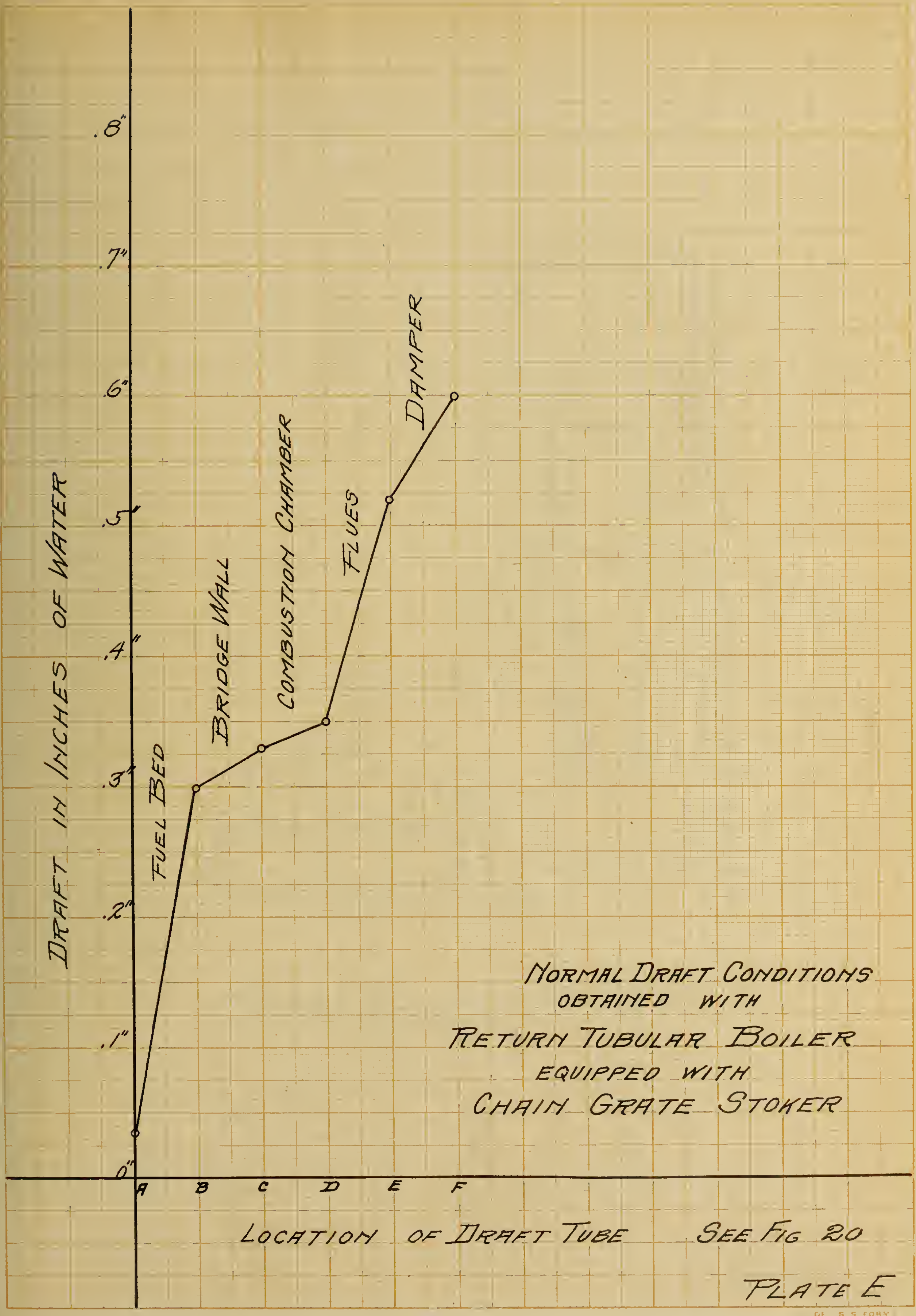


DIAGRAM OF RETURN TUBULAR BOILER
FIG. 20


.8"
.7"
.6"
.5"
.4"
.3"
.2"
.1"
0"
DRAFT IN INCHES OF WATER
FUEL BED
BRIDGE WALL
COMBUSTION CHAMBER
FLUES
DAMPER
NORMAL DRAFT CONDITIONS
OBTAINED WITH
RETURN TUBULAR BOILER
EQUIPPED WITH
CHAIN GRATE STOKER
A
B
C
D
E
F
LOCATION OF DRAFT TUBE
SEE FIG 20
PLATE E

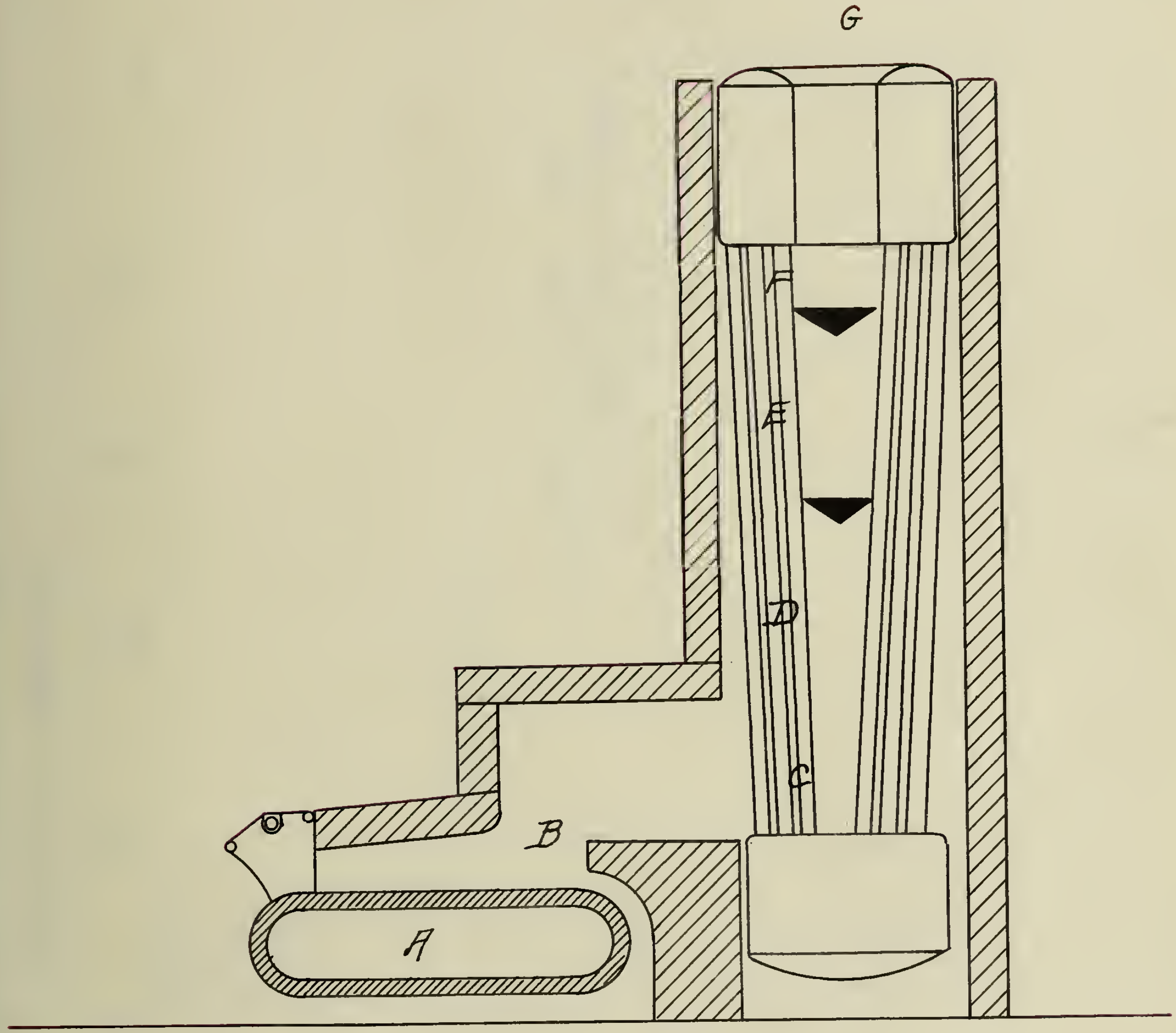


DIAGRAM OF CAHALL VERTICAL BOILER
FIG. 21

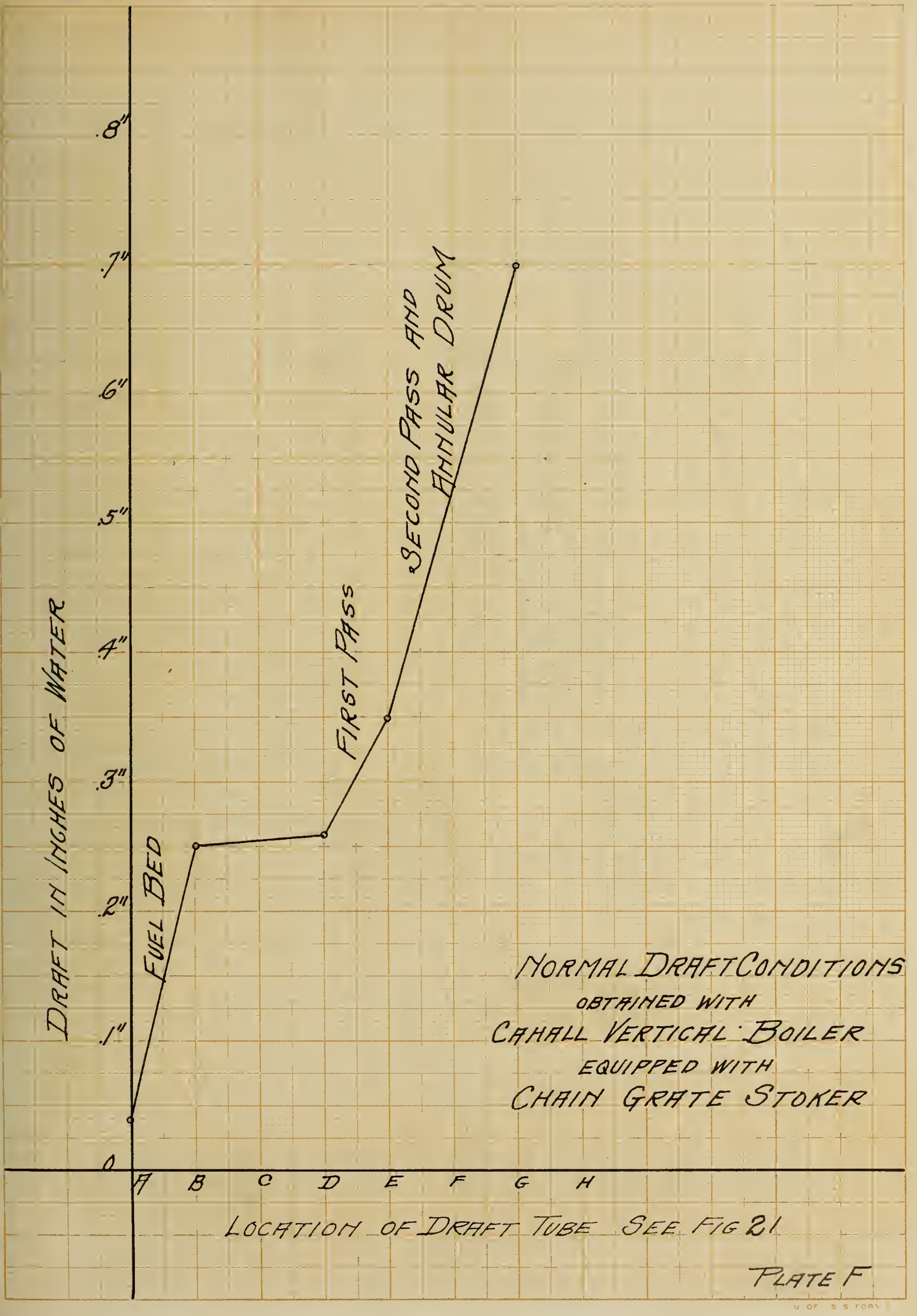

Draft in Inches of Water
.8"
.7"
.6"
.5"
.4"
.3"
.2"
.1"
0
Fuel Bed
First Pass
Second Pass and
Annular Drum
A B C D E F G H
Location of Draft Tube See Fig 21
Normal Draft Conditions
obtained with
Cahall Vertical Boiler
equipped with
Chain Grate Stoker

Plate F

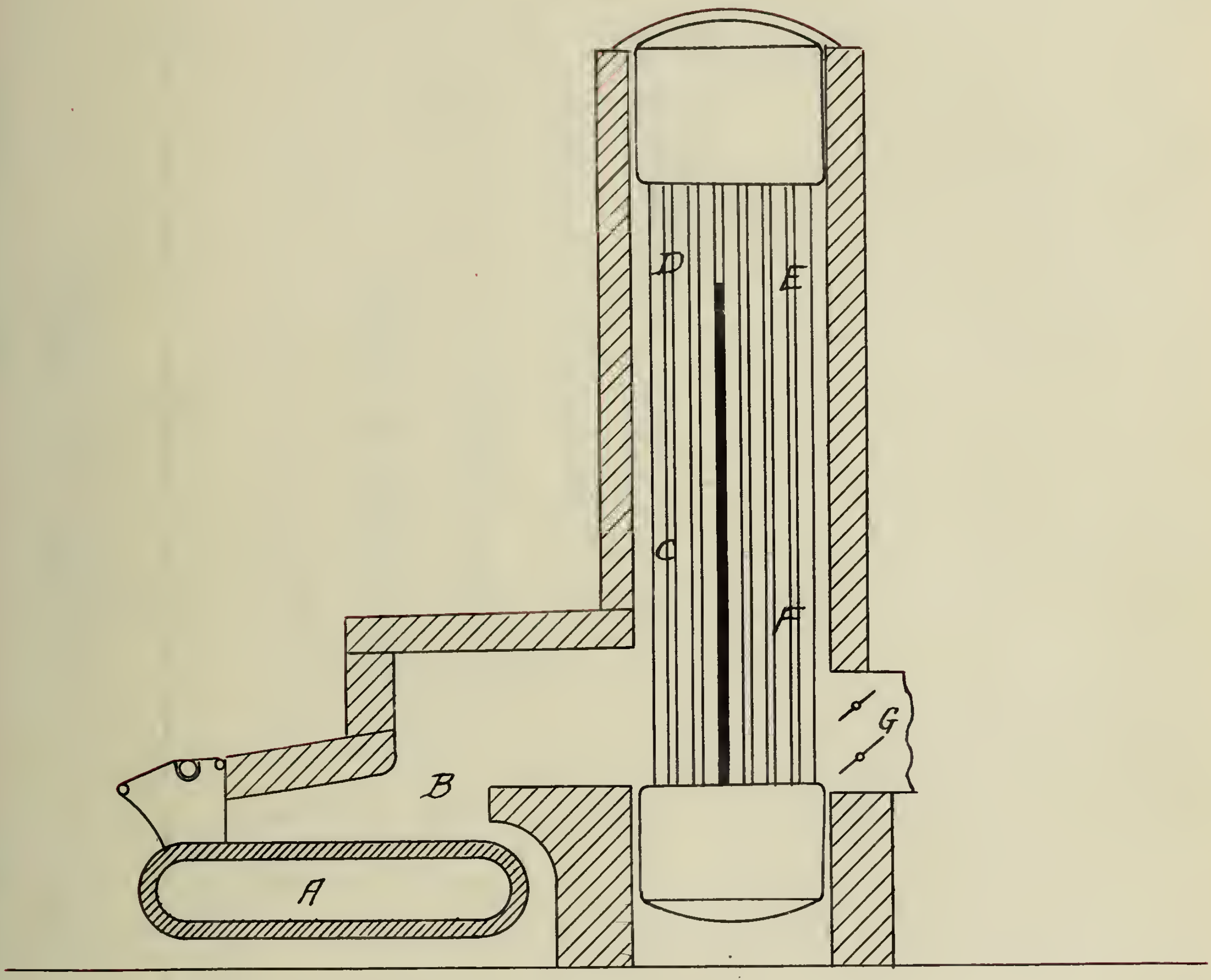
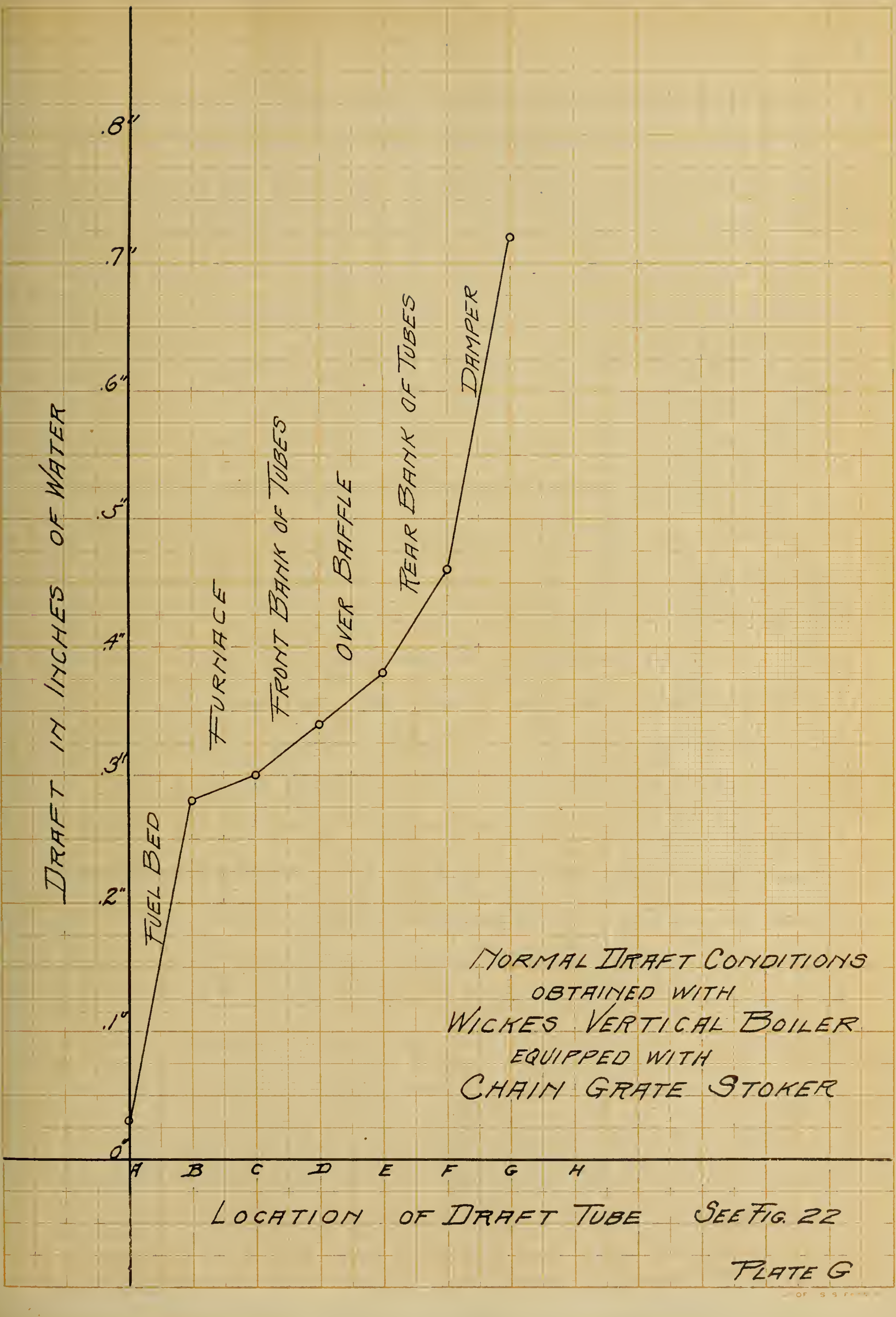


DIAGRAM OF WICKES VERTICAL BOILER
FIG 22


.8"
.7"
.6"
.5"
.4"
.3"
.2"
.1"
0"
DRAFT IN INCHES OF WATER
FUEL BED
FURNACE
FRONT BANK OF TUBES
OVER BAFFLE
REAR BANK OF TUBES
DAMPER
NORMAL DRAFT CONDITIONS
OBTAINED WITH
WICKES VERTICAL BOILER
EQUIPPED WITH
CHAIN GRATE STOKER
A
B
C
D
E
F
G
H
LOCATION OF DRAFT TUBE
SEE FIG. 22
PLATE G

In practice good conditions are obtained with an area equal to one-quarter of the grate surface at the section at which the gases leave the furnace, (with a Heine boiler this area is between the bridgewall and the tile roof, with a Babcock & Wilcox or Stirling boiler, it is the net area of the first pass) and an area of one-sixth of the grate surface at the damper opening. The breeching and stack area may be one-seventh of the entire grate surface. All intermediate points between the furnace and damper are proportioned on gradually decreasing areas between one-fourth and one-sixth of the grate surface. If these ratios are maintained, no undue drop of pressure will occur, due to restriction, and the normal difference in potential for the type of boiler under consideration may be taken from the standard curves.

Chain grate sizes are proportioned on the ability to deliver certain required amounts of heat to the boiler.

The problem starts with the available difference in potential between the furnace and ash pit and the corresponding rate of combustion. It has been determined from numerous trials that the rate of combustion of dry coal per unit of draft on the Chain Grate burning bituminous slack is a very nearly straight line curve - Plate L. This will be modified by coals high in ash and coals low in volatile. Such coals are usually slow to ignite and cannot be as rapidly burned as can a coal higher in volatile, but as a general figure it is assumed that there will be a consumption of one pound of dry coal per square foot of grate surface for each

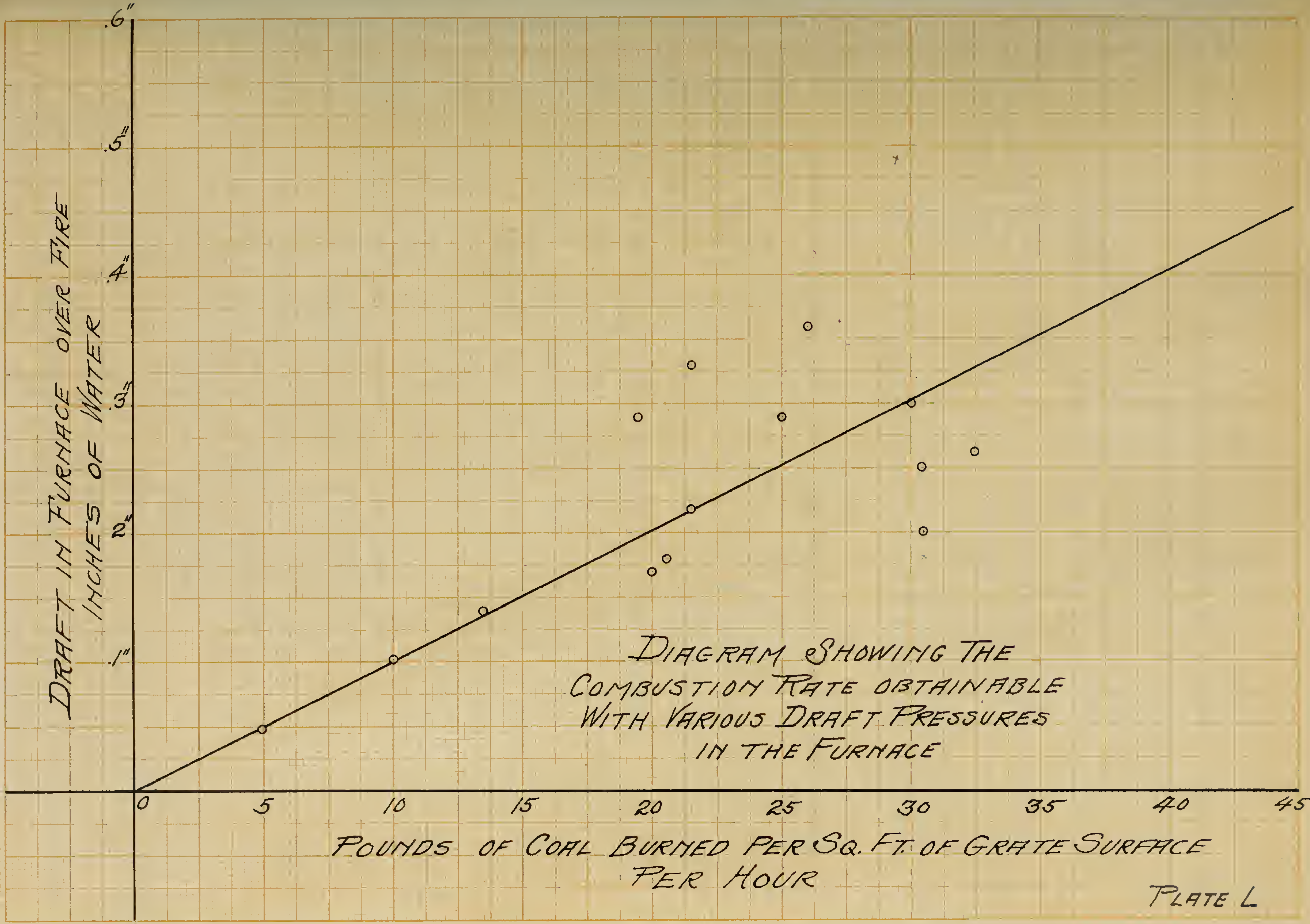

DRAFT IN FURNACE OVER FIRE
INCHES OF WATER
.6"
.5"
.4"
.3"
.2"
.1"
0
5
10
15
20
25
30
35
40
45
DIAGRAM SHOWING THE
COMBUSTION RATE OBTAINABLE
WITH VARIOUS DRAFT PRESSURES
IN THE FURNACE
POUNDS OF COAL BURNED PER SQ. FT. OF GRATE SURFACE
PER HOUR

PLATE L

.01 inch of draft in inches of water in the furnace. The first step, then is to deduct from draft pressure in the base of the chimney the difference in potential due to the effect of the passage through the breeching and in the boiler, thus arriving at the available difference in potential between the furnace and ash pit, or what is commonly known as draft in the furnace. Then for each.01 inch of draft in the furnace,one pound of dry coal may be burned per hour for each square foot of grate surface.

Suppose it were desired to serve a 500 H. P. Babcock & Wilcox boiler with a Chain Grate, fifty per cent overload being desired, the fuel being Illinois washed pea of 12,000 B.T.U. per pound dry, the breeching being of steel, circular section and fifty feet long, with three right angle bends:-

Required horse power to be developed-------------750

Pounds of coal required per horse power hour
(assuming 65 per cent efficiency)-------------4.2

Hourly coal consumption required - pounds-------3150

Draft required in furnace--------------------------.30 in.

Grate surface required for consumption of
3150 pounds of coal hourly with .30 inch
draft---------------------------------------100 sq. ft.

Proportions of grate surface, 10'-0" wide x 10'-0" long.

CHIMNEY CALCULATIONS

Difference in potential required in furnace---------.30 in.

Loss due to diminished velocity through setting -
(See Plate B)--------------------------------.34 in.

Losses occurring in 50 feet of breeching-----------.05 in.

Losses due to three right-angle bends--------------.15 in.

Required net pressure to be exerted by atmosphere at base of the chimney------------------.84 in.

Height of chimney required (assuming 500 degrees chimney temperature)----------------------150 ft.

Diameter required (based on 5 pounds of coal per horse power)----------------------------66 in.

OPERATION

In the ensuing pages the writer desires to set forth the correct procedure for starting a new installation, giving firing rules,and discussing the best methods of handling various types of boiler loads.

In starting a new installation it is well to operate the Chain grates cold for a day or two, to insure their proper mechanical operation. If steam is obtainable, this is a simple matter, otherwise it is necessary to operate the machine by hand. The representative in charge should then inspect, not only the furnace, but also the boiler, inside and out, and the breeching, assuring himself that the damper fits well and operates freely, and that water flows through the waterback unrestricted. After running the machine cold for a day, a slow fire may be put under the boiler. The fire is started in the following manner:-

Close the damper two thirds, set the stoker gate at a height of six inches, and run in twenty four inches of coal. Then thrust some kindling under the stoker gate and on top

of the coal bed. Leave the ends projecting out over the front of the grate. Then obtain some oily waste from the engine room, and lay some under the kindling, ignite and run the grate slowly forward until the ignited kindling is under the arch in the furnace. Then stop the machine and allow the coal to burn and heat the igniting arch. The secret of starting fires is the heating of the igniting arch. In the course of ten or fifteen minutes the coal will be well ignited, and the arch will be sufficiently warm to sustain a weak ignition. Coal may now be thrown in the hopper and the grate slowly operated, care being taken not to allow the ignition to "creep away" from the front of the arch. As soon as the entire grate surface is covered with ignited coal, the damper may be opened. The furnace temperature will rapidly increase, and normal operation may be started.

Attention should at this point be given to the thickness of the fuel bed. In general it may be stated that the thicker the fuel bed, the higher the CO-2 found in the gases, and the better the economy. With washed nut or slack, fuel beds of nine inches in thickness can be economically used. With ordinary screenings with 10 per cent to 15 per cent ash, a fuel bed of six inches or seven inches in thickness is usually as much as can be used. With coals containing 20 per cent to 30 per cent of refuse, it frequently occurs fuel beds of two inches to three inches in thickness are required.

Thickness of fuel bed is also very dependent on draft and size of coal. With settings having a low available draft,

a thinner fuel bed is necessary, as it requires a greater difference in potential to force air through the thick one. Large, clean coal requires thicker fires than small sized coal or slack, the reason being that the air passes through the former more readily.

In any setting with a specified coal and draft there is a certain best condition of fire that requires practice to obtain. Should the fire tend to burn "short", i. e., to leave a bare space on the rear end of the grate, covered only by completely burned ash when the grate is operated at normal speed of two inches per minute, it is evident that the gate should be raised, and a thicker fuel bed should be tried. The thickness should be increased up to a point where at the slowest operative speed of the machine (approximately one inch per minute) the fuel is not completely burned before reaching the end of the grate. The economy of thick fires occurs on account of the increased depth of fuel bed cutting off the amount of free air entering the furnace during the early stages of combustion, and also the increased depth of ash bed at the rear of the stoker,making a more effective air seal at that section than the thin ash bed. Moreover there is less danger of holes occurring in the thick fuel bed than in the thin. The economy of high CO-2, however best obtained is shown very clearly from the chart shown in Plate R, which has recently come to the writer's attention. The curve representing the furnace temperature may be considered as a boiler efficiency curve, or a curve of efficiencies based on the com-

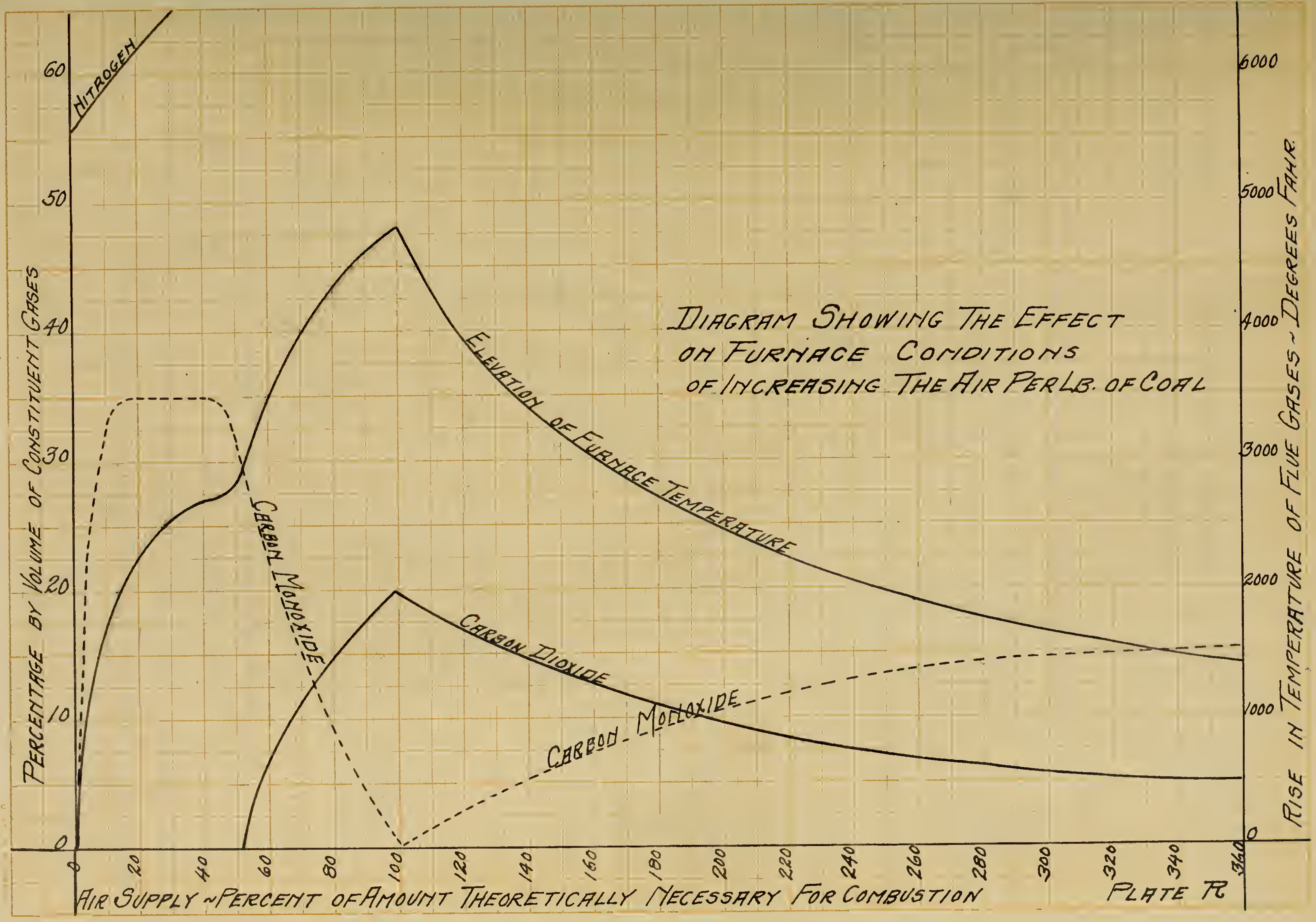


Diagram Showing The Effect
on Furnace Conditions
of Increasing The Air Per Lb. of Coal
Nitrogen
Elevation of Furnace Temperature
Carbon Monoxide
Carbon Dioxide
Carbon - Monoxide
Percentage by Volume of Constituent Gases
Rise in Temperature of Flue Gases ~ Degrees Fahr.
Air Supply ~ Percent of Amount Theoretically Necessary For Combustion
0
10
20
30
40
50
60
1000
2000
3000
4000
5000
6000
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
Plate R

bustible in the coal, the most favorable conditions being obtained with high furnace temperatures.

SIZE OF COAL

Mr. W. L. Abbott, in a paper, "Some Characteristics of Coal as Affecting the Performance of Steam Boilers," W. S. M. E., Sept. 15, 1906, brings out the points that with the particular installation under his observation, washed coal of three-quarter size produced the maximum results both as regards efficiency and capacity. The writer's experience has been coincident with Mr. Abbott's regarding this item, maximum results always being obtained with washed pea and nut coal of the size that passed through a seven-eighths inch screen, and over a nine-sixteenth inch screen. Uniformity in size of coal is very essential, as large lumps do not burn with the same rapidity as do the smaller pieces, thus giving rise to either coke in the ash pit, or bare spots on the grate.

PREPARING FOR A COMMERCIAL TEST

Much has been written regarding the conduction of evaporation tests from the standpoint of a Consulting Engineer. The American Society of Mechanical Engineers has fully and completely standardized each item, leaving no question regarding the manner of conducting tests, observing data, or calculating results. The writer wishes to view the test from the standpoint of a representative of the stoker company sent out to fairly obtain a certain guaranteed efficiency and capacity.

The representative should thoroughly acquaint himself with the guarantees, obtain all data relative to heating surface, grate surface, areas of passes, breeching and stack dimensions, and study them carefully. He should calculate the required rate of combustion necessary to produce the specified rating, and discuss with his superior the best past practice in obtaining such combustion. He should have a definite understanding with the owner or the engineers in charge regarding the purpose of the tests, and the manner of procedure in making same. On arriving at the installation he should (unless certain coal is specified in the guarantee) obtain information regarding the coal,preferably having a preliminary sample analyzed. He should investigate the furnace very thoroughly before firing, assuring himself that all tube tile, baffles, and flame plates are in place, and that there is no possibility of the gases short-circuiting through the setting. He should see that the damper swings freely and that it has certain definite marks indicating its degree of openness; also that all cracks in the brickwork are pointed up with mortar or asbestos, and the setting, if apparently porous, given a couple of heavy coats of whitewash. All doors must fit absolutely tight, and asbestos wool must be stuffed between headers. No stone should be left unturned in preventing the infiltration of air through the boiler setting. He must be absolutely positive of the effectiveness of the internal damper of the stoker, and the correctness of the waterback position. This being done, he must make a thorough inspection of the

heating surface, being positive of its perfect condition as regards absence of scale inside, and soot outside.

He may then fire up and make a preliminary run, weighing water and coal, having his fireman present, if possible, and taking fifteen minute readings of CO-2, O and CO, flue gas temperature and draft throughout the setting.

The purpose of this preliminary run is to learn the most economical conditions, and to establish certain fuel bed thickness, rate of travel, per cent of CO-2 and O, and flue gas temperature obtained thereby. When the desired conditions are obtained, careful note should be made thereof, and the representative may inform the purchaser or his engineer that he is ready to make the guarantee test.

During the test proper inspection should be made of all items as regards weighing apparatus, records, etc., to insure that everything is done in accordance with the standard code, but the main item is to see that the established conditions are maintained.

Observations of CO-2, draft and flue gas temperatures should be made at intervals of fifteen minutes, and the representative should let no reading go uninspected. During the test he should occupy no particular station, but should keep a general inspection, keeping hourly tab on the estimated efficiency and horse power developed.

It should be ever borne in mind that the investigation and test in themselves have little value, since the economies obtained with Chain Grates are well known and established

values, but that the information is to prove instructive to the operative force, and to reduce the existing coal consumption.

As an example of a plant operated on established test conditions, the writer calls attention to work done in a large station in the Middle West. In this plant are forty vertically baffled boilers of 518 H. P. capacity, and equipped with Chain Grates. The boiler settings are identical, and the draft pressure at the damper does not vary .05 inches through the entire installation. The boiler room layout is such that it is practically impossible to inspect the condition of any of the fires, with the exception of eight settings, leaving thirty-two "blind settings."

In order to learn the most economical conditions, exhaustive evaporative tests were conducted, varying the air supply as controlled by the damper, the thickness of fuel bed and the rate of travel. During these tests careful observation was made of the draft, CO-2, and flue gas temperature. After some pleasing economies had been obtained, the conditions producing such economies were established throughout the boiler room. These conditions were on this particular setting - 6 inch fuel bed of slack coal,

.25 inch to .30 inch draft in the furnace,

12 to 14 per cent carbon dioxide.

Each furnace was equipped with an individual draft gauge of the Ellison differential type, permanently connected by one-quarter inch pipe to the furnace, entering through a hollow

stay-bolt in the front header.

It was conclusively proven that a six inch fire of proper condition gave a draft resistance of .25 inch to .30 inch, any excess of this amount always indicating that the fuel was piling up against the bridgewall, either because of the overhang melting or partially closing the aperture, or because the rate of travel of the grate was too fast, in either case easily remedied. Any draft reading below .25 inch indicated either a bare spot on the grate or a short fire , in nine cases out of ten the latter.

By making investigation of each individual setting, it was proven that the per cent of CO-2 varied directly as the length of the fire, the maximum reading being 14 to 15 per cent with a full fire, and 1 or 2 per cent with a fire 2 feet long. Plate S shows a graphical representation of the draft and CO-2 relations in boilers Nos. 1 and 2.

The operative force was then instructed by means of a test made on a setting having all inspection holes closed, and the furnace conditions indicated solely by the draft gauge. The test proved very successful, both regarding efficiency and capacity, and thereafter all "blind settings" were operated in this manner with very satisfactory results. Periodically all settings are investigated by means of an Orsat to determine if air leaks exist, any readings out of line with draft readings being indications of such. The curves shown in Plate S represent the relation of draft in furnace to CO-2 in the rear of two typical boiler settings,

samples being taken from the third pass through an upper hollow stay-bolt in the rear header.

It will be noted that for any draft condition on No. 1, the per cent of CO-2 was different from that obtained from boiler No. 2. This the writer attributes to air leaks existing in the boiler setting, such as around cleaning doors or soot doors, through hollow stay-bolts, etc., and the distance from the origin at which each curve (prolonged) in Plate S intercepts the base line may be considered to represent the relative tightness of that boiler setting. The fact that theoretically such curves would pass through the zero point has not been overlooked, but this length of intercept may be used to represent the condition of settings as regards tightness.

Referring again to Plate S, it will be noticed that the reduction in velocity occasioned by the existing air leaks is the indicated distance of A - B, or .43 inch of water in the furnace. The above procedure obtained good results in practice, and brought to light many otherwise unnoticed bad conditions. It is now no unusual procedure to operate fires largely by draft gauges, this merely being a case more thoroughly developed than the usual.

Careful study must be made of the style of boiler load existing in any plant, with the idea of operating the boilers to the best advantage thereto. It is easily possible to have in a plant several units economical in themselves if operated at certain ratings, and yet because of undue over-

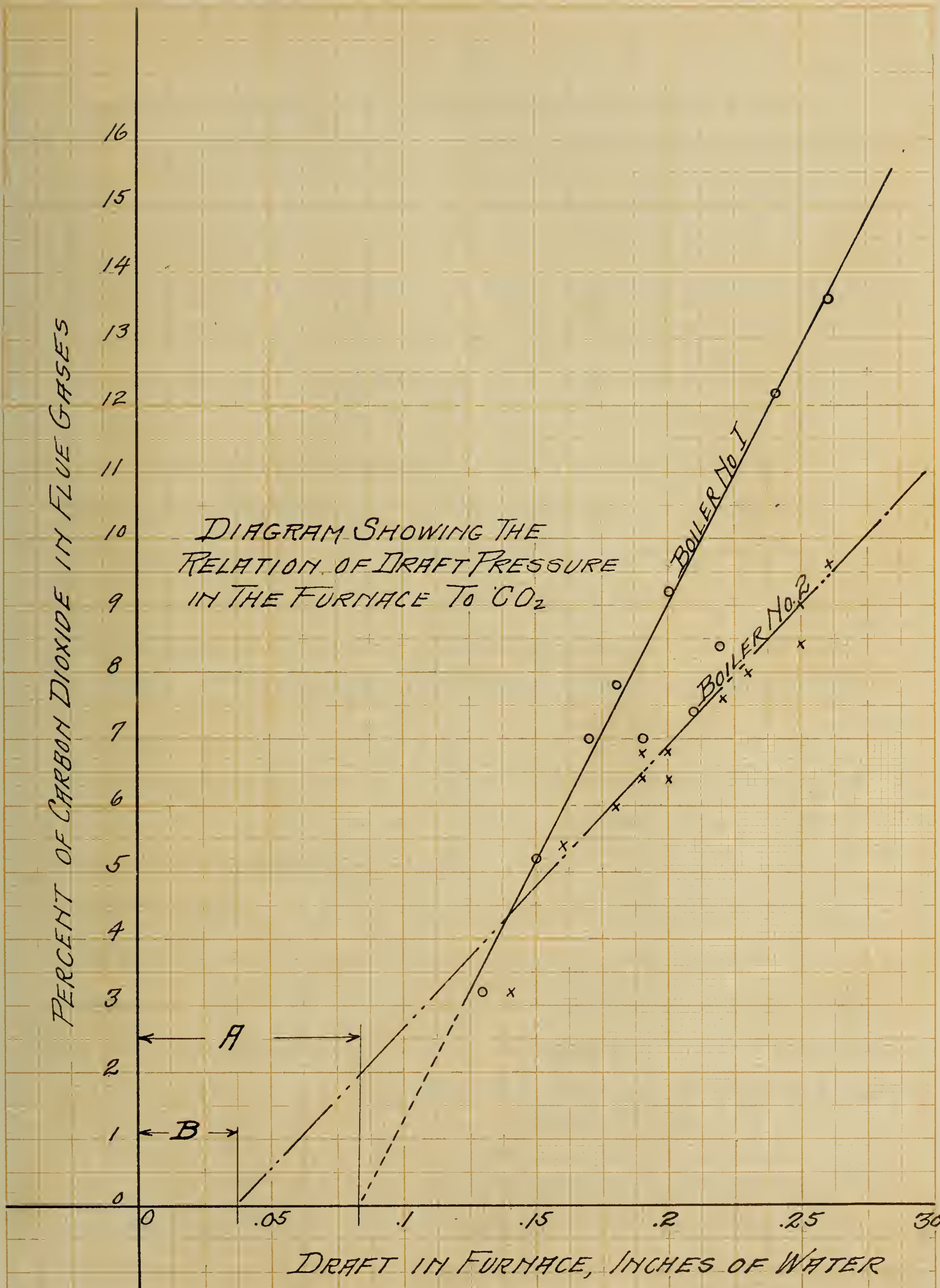


DIAGRAM SHOWING THE
RELATION OF DRAFT PRESSURE
IN THE FURNACE TO CO_2
PERCENT OF CARBON DIOXIDE IN FLUE GASES
DRAFT IN FURNACE, INCHES OF WATER
BOILER No. I
BOILER No. 2
A
B
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
.05
.1
.15
.2
.25
30

PLATE S

loads or underloads, the economy as a whole may be poor.

A condition exists in connection with electric light and power loads requiring special attention. The electrical load in such plants quite often is similar to that shown on Plate T_3. It is necessary to learn the most economical rating of the boilers and furnaces, and attempt to operate them at such ratings. The load in this case may be very closely anticipated, and should at all times be carried with just sufficient boilers to permit of their being operated at this point of economy. As the peaks come on, boilers must be warmed up and fires run back until they cover the entire grate, and as required the dampers on such boilers may be opened and the boilers cut in to the steam line. From a banked fire it requires about thirty minutes to heat up the setting to a point at which the boiler is making its full rating, so that steam requirements must be anticipated this amount of time in advance, and fires operated accordingly. As the peak drops off to a point at which the safetys are about to pop, one boiler may be cut out by allowing the coal hopper to run empty, stopping the grate, and closing the damper. One after another boilers may be cut out in this manner, and with hoppers empty to a point just preventing air from entering under the gate, will stand for six to eight hours without further attention.

A different class of boiler loads is that existing in breweries, starch manufacturing plants, or any plant having live steam cookers. In such cases the boiler load curve

is fairly constant, with the exception of these short sharp peaks due to the opening of a steam line into a cooker or a brewing vat. In order that such demands for steam may be met successfully, it is essential that signals (usually by ringing of a bell) be given to the boiler room thirty minutes, and five minutes in advance of opening the line. At the first signal the operator fills the hoppers and starts the machine. At the five minute bell he opens the damper. The duration of such peaks is usually constant, and after a few trials the operator can drop the peak without popping off by carrying low water and cutting out the stoker slightly in advance of the termination of the peak.

Machine shop loads are fairly constant during working hours, being entirely off between such. In these cases it is possible to bank the fires twenty minutes before the load comes off, carrying the load upon the heat in the water and furnace. When the engines are stopped the water will be low, the fires short, and the settings comparatively cool. Then by starting the pumps the boilers may be prevented from popping off.

In order to insure the correct handling of boilers, it is essential to keep a log, and the writer recommends one similar to that shown in Plates T_1, T_2 and T_3. This log is applied to an electric light and power load, but might easily be adapted to various conditions. The upper part, Plate T_1, of this log sheet is filled out from data submitted on proper forms by the boiler room foreman at the termination of each shift.

The engine and electrical data, Plate T_2, is furnished by the switch-board operator. The coal consumption is an estimate made from the number of skip buckets elevated to the bunker. The correct coal per K. W. hour is not known until the end of the month, when the car-load weights are totaled. The operation of the boilers as shown on the log, Plate T_3, is very poor, too much capacity being employed at all times. The boiler capacity curve should have followed close to the engine capacity curve. It may be stated that this was a representative log of operative conditions on a plant at the time of the introduction of this style of log. The economy increased in a very marked manner by using boiler and engine capacity consistent with the load carried. The use of such logs will develop correct operation. The operating force may be shown just how many boilers are to be permitted at any time, and in a short time learn to operate accordingly.

In addition to such operative reports, report should be made on items of washing boilers, blowing soot, cleaning combustion chamber, making furnace repairs, and such other items as arise periodically.

STOKER TROUBLES

The troubles encountered with Chain Grates may be broadly divided into two classes, viz., economic troubles and mechanical troubles. By far the most common cause of all such trouble is insufficient air, which in turn resolves itself into a question of insufficient difference in pressure

SHEET 1

BIRMINGHAM RAILWAY LIGHT & POWER CO
POWER STATION REPORT

DATE JUNE 25, 1907

LEGEND
TOP OF SPACE — — BOILER IN
MIDDLE " " — — — — " BANKED
BOTTOM " " — — — — " OUT

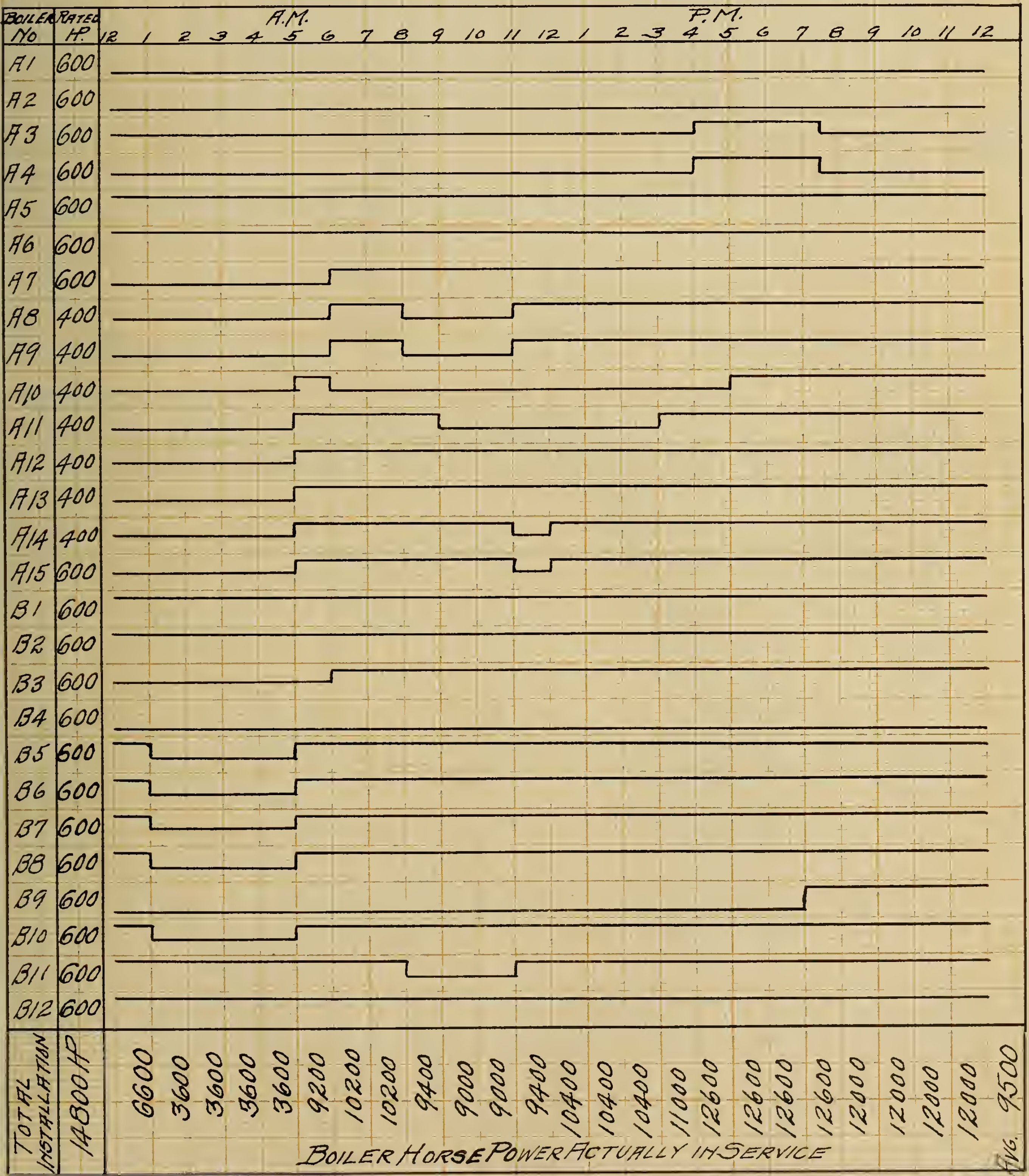


PLATE T1

Sheet 2

Birmingham Railway Light & Power Co.
Power Station Report

Date June 25 1907

Engines.

Engine No.	H.P.
1	2133
2	1133
3	1133
4	533
5	2000
6	2000
Turbine No	
1	4500
2	4500

Hours: A.M. 12 1 2 3 4 5 6 7 8 9 10 11 12 P.M. 1 2 3 4 5 6 7 8 9 10 11 12

Total Installation 17932 HP

4500 4500 2000 2000 2000 2000 2000 3633 3633 4633 5266 5266 5266 5266 5266 5266 5266 5266 5133 5633 7633 7633 7633 7633 6500 6500 4500 4500 4500

Avg 4800

Plate T2

Sheet 3

Birmingham Railway Light & Power Co.
Power Station Report

Date June 25, 1905.

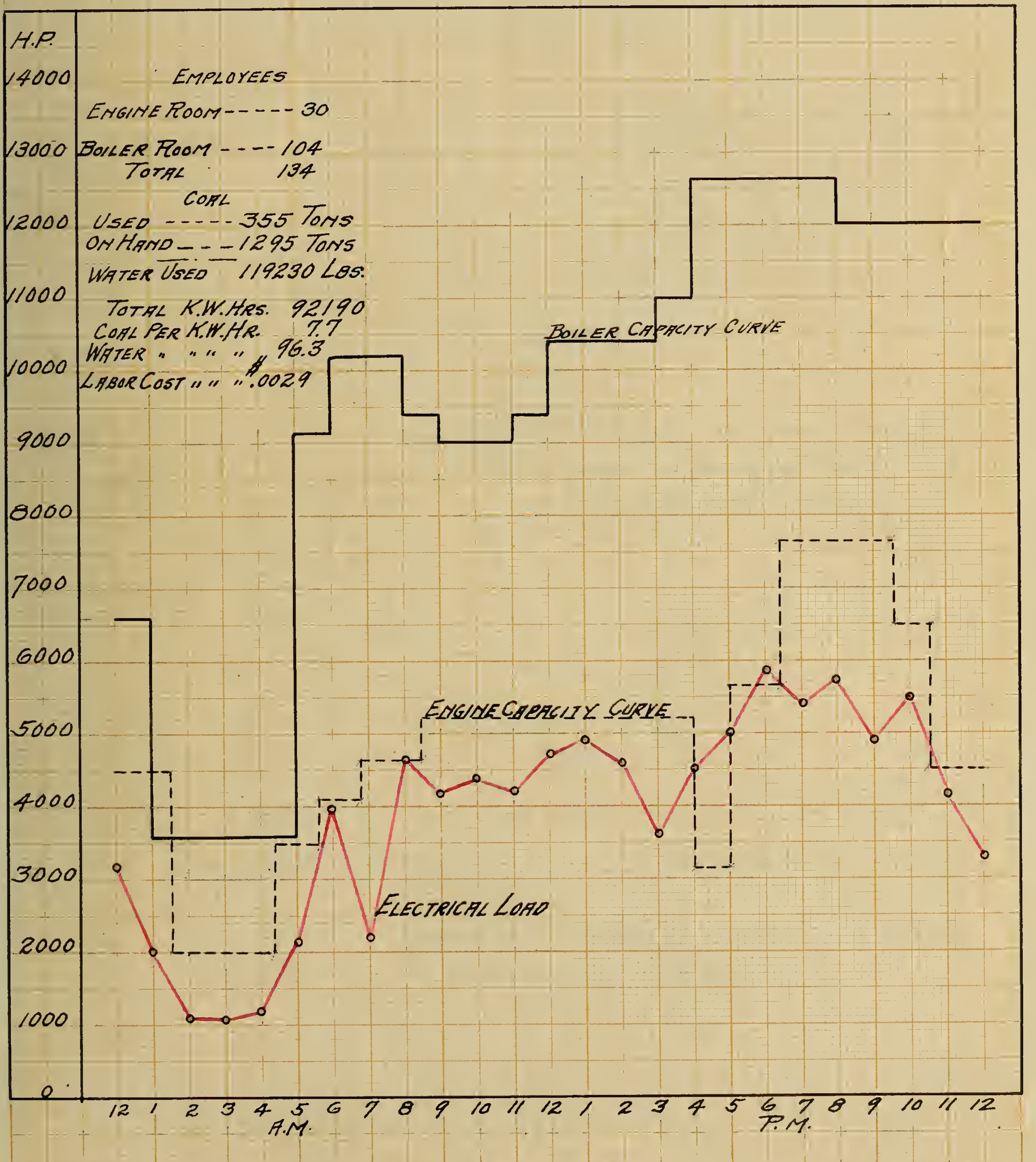
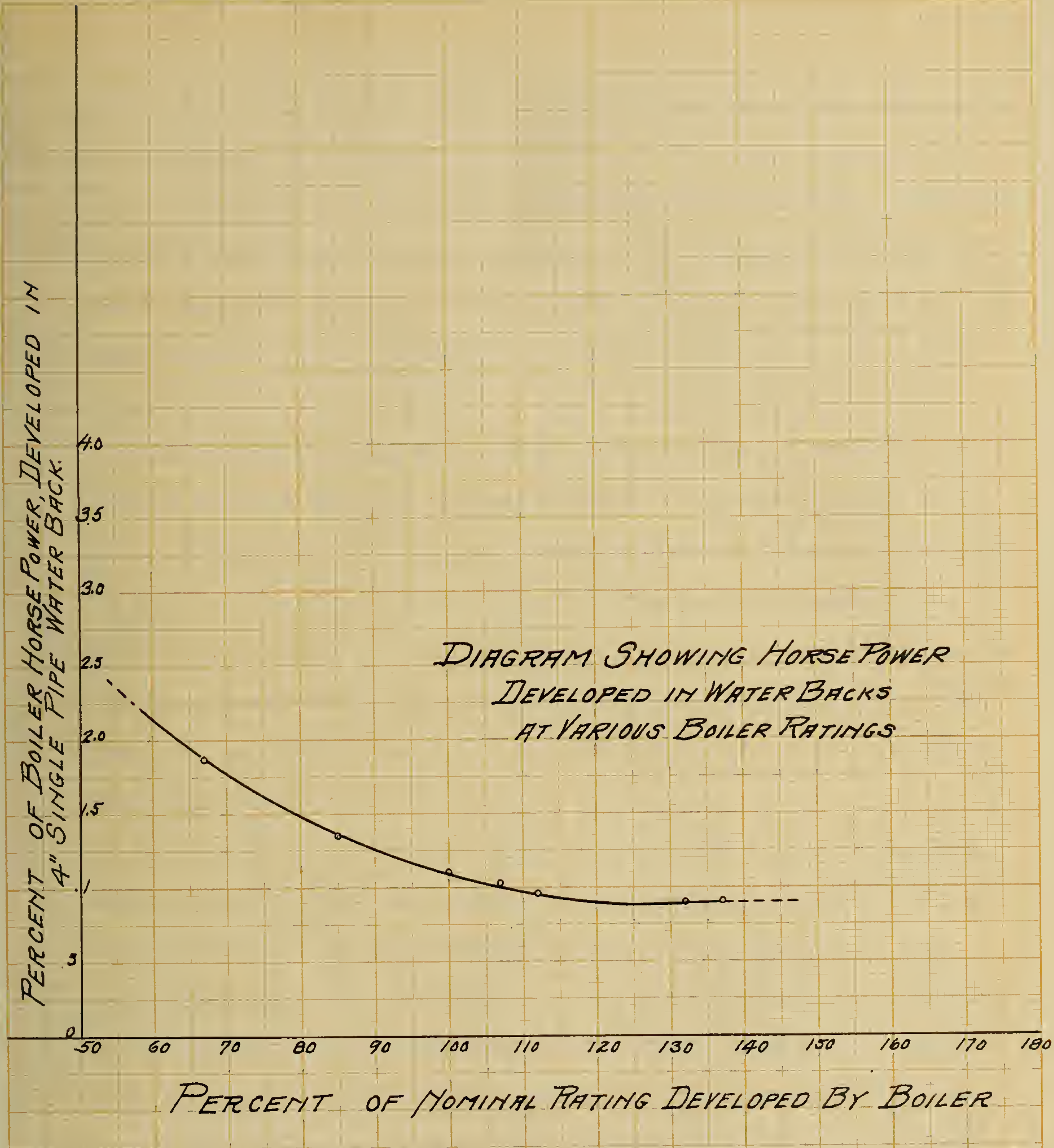


Plate T3



DATA FROM TESTS 129-135 ILLINOIS UNIV.
COMPILED BY H.B. DIRKS M.E.

PLATE X

from ash pit to furnace and is commonly spoken of as low draft, as discussed in a preceeding chapter. The coal consumption, and necessarily the horse power developed are directly proportionate to the draft in the furnace. The limits of operative draft may generally be stated as .40 inch for a maximum and .20 inch minimum, with the ratios and proportions of present practice.

Mr. Bement in a paper "Some Performances of Boilers and Chain Grate Stokers, with Suggestions for Improvement," W. S. M. E., February, 1904, shows results obtained from a series of trials to determine the effect of furnace draft upon efficiency and capacity. The maximum efficiency was obtained with .20 inch draft in the furnace, the economy gradually decreasing with increased draft. The maximum capacity was obtained with .40 inch.

There is considerable discussion at this time of higher rates of combustion per square foot of grate surface. This will not apply to Chain Grates as at present designed, for the reason that the ignition of the incoming fuel is inductive and dependent on grate speed and fuel bed thickness. It is safe to say that the present design of Chain Grates will not permit of greater fuel consumption,regardless of draft, than forty pounds of dry coal per square foot of grate surface per hour.

In all instances that have come under the writer's observation, the capacity reaches the maximum at about .40 inch furnace draft. Any additional draft merely forces

excess air through the fuel bed, lowering the furnace temperature in the case of some coals sufficiently to prevent continuous ignition. As regards the furnace draft consistent with maximum economy, the writer has found this item to be a quantity varying with the nature of the heating surface, the proportion of grate surface to heating surface, and the areas of the various passes of the boiler. However, the most successful tests have been made with a draft of from .25 inch to .30 inch in the furnace. With present standard ratios at least .20 inch draft is required to produce the rating of the boiler, and settings not making considerably above rating in practice are usually considered failures. Furnace drafts below .20 inch are very apt to give rise to excessive coke in the ash, the draft not being sufficiently intense to burn the coal properly. To avoid this and the piling up of the coal against the bridgewall, thinner fires are sometimes resorted to, with consequent loss in economy, due to the greater difficulty in keeping the grate properly covered. The piling up of ignited coke against the bridgewall, or the presence of hot coke in the ash, if allowed to accumulate until it reaches the chain, are conditions that give rise to burnt chains, caused by the links forcing their way through the burning coal. This in a short time destroys the chain.

Low draft, caused by a throttling of a draft area of the boiler setting, particularly if such throttled pass be close to the combustion chamber, causes very serious results.

The effect is the retention of the heat in the furnace, causing excessively hot chains and side walls. In some cases this is so severe as to limit the life of the chain to a few weeks, and to burn down the side walls and igniting arch in as short an interval. The cause of this trouble may be located by the use of a draft gauge, and the comparison of the readings obtained to the standard curves discussed in a preceding chapter.

Following is a tabulation of the troubles that are encountered in connection with Chain Grate installations. The writer has arranged these under the headings of Effect, Cause, and Remedy, hoping that this arrangement may prove useful notebook information in visiting plants to others, as it has been to the writer.

CHAIN RUNNING HOT

Effect:

Burns links.

Cause:

(a) Ash pit full of hot ashes.

(b) Hot coal piling against waterback on bridgewall.

(c) Retention of gases in furnace.

(d) Too long or low roof in "dutch oven" settings.

Remedy:

Cause (a) Empty ash pit more frequently, or design larger pits.

Cause (b) Run fires so as not to cause bank at rear.

Cause (c) Open up baffling at point where throttling occurs.

Cause (d) Can only be remedied by resetting roof higher.

WEAK IGNITION

Effect:

1. Fire cannot be forced.
2. Cuts down grate effective surface.

Cause:

(a) Low furnace temperature.

(b) Wrong slope to arch.

(c) Coal low in volatile.

(d) Very low grade coal (high ash).

(e) Excessive air through zone of ignition.

Remedy:

Cause (a) See "Low Furnace Temperatures."

Cause (b) Change arch to suit coal (Reduce slope).

Cause (c) Use coal with higher volatile.

Cause (d) Use large grate surface and strong arch effect, rather thin fires.

Cause (e) Arch or gate must be made tight, and air supply cut off.

HIGH FLUE GAS TEMPERATURE

Effect:

Reduces efficiency.

Cause:

(a) Dirty boiler.

(b) Admission of cold air through setting.

(c) Insufficient heating surface to absorb heat.

(d) Short circuit in boiler.

(e) Excessive over rating.

(f) Excessive draft in furnace.

(g) Air leaks through fuel beds.

Remedy:

(a) Apparent.

(b) Apparent.

(c) Put in extra pass for gases.

(d) Repair baffles.

(e) Determine whether boiler is operating at most economical rating.

(f) Causing either (e) or (b) or (c).

(g) Keep grate covered.

LOW FURNACE TEMPERATURE

Effect:

1. Poor ignition.
2. Poor combustion.
3. Smoke.

Cause:

(a) Incomplete combustion.

(b) Grate surface too small for heating surface.

(c) Furnace too large, temperature falls as gas expands.

(d) Low grade coal.

Remedy:

(a) Redesign furnace.

(b) and (c) Put in larger grate.

(d) Use better coal or large grate and strong arch effect with thin fires.

LOW CAPACITY

Effect:

Boilers not making ratings.

Cause:

(a) Draft x square feet grate surface gives product less than the number of pounds of coal required to make rating.

(b) Low grade coal.

(c) Dirty boiler.

(d) Sometimes low efficiency.

Remedy:

(a) Increase grate area or draft.

(b. c. and d.) Apparent.

LOW EFFICIENCY

Effect:

High rate of coal per horse power hour.

Cause:

(a) Incomplete combustion. Coke in ash.

(b) High flue gas temperature.

(c) Dirty boiler.

(d) Air leaks in setting.

(e) High CO_2.

(f) Thin fires.

(g) Unburned hydro-carbons.

Remedy:

(a) Increase draft.

(b) Clean tubes. Look for air leaks in furnace and through fuel bed.

(c) Clean tubes.

(d) Stop air leaks.

(e) More air, and proper mixing at high temperature.

(f) Thicker fires.

(g) Can only be remedied by redesigning furnace.

UNDULY HIGH TEMPERATURE OF FURNACE WALLS AND GRATES

Effect:

Short life of chain and side walls, due to excessive heat.

Cause:

Confining heat in furnace by

(a) Throttling areas through the boiler setting.

(b) Admitting cold air to enter setting back of furnaces.

Remedy:

(a) Proportion areas correctly.

(b) Cut off air admission.

COKE IN ASH

Effect:

Low efficiency.

Cause:

(a) Forcing boilers beyond capacity, i. e., burning more coal than (G. S. x draft).

(b) High waterback.

(c) Coking coal.

(d) Thin fire and fast grate.

Remedy:

(a) Increase grate surface, or draft.

(b) Lower waterback.

(c) Use free burning coal.

(d) Use thicker and slower fires. Look for slow ignition.

LOW CO-2 WITH HIGH O.

Effect:

Low efficiency.

Cause:

Excess air entering either through fire or through setting.

Remedy:

Thick fires. Stop all possible air leaks. Cover setting with asbestos.

Under the heading of low furnace temperatures, it should be noted here that a furnace having roof and walls of refractory material is not sufficient to insure high temperature, unless the proper ratios of cross sectional areas exist throughout the combustion chamber. The uniformity of areas, or a

gradual increasing area as the gases travel along, must be provided, and the sudden increase in cross section must be carefully avoided if continuous high temperatures are desired. It is sometimes noted even with good coal and good draft, dull red flames and smoky conditions exist, due to the sudden increase in cross section of the furnace, causing an expansion of the gases and a corresponding decrease of the temperature. It has been noted in three distinct cases under the writer's observation that an increase of 100 per cent in area practically prevented continuous combustion by failing to generate sufficiently high remperatures to sustain a continuous ignition. A sudden increase of 50 per cent in cross section rendered it impossible to get bright, white fires, but when a furnace area was provided giving an increase of only 15 or 20 per cent in cross section at any point, high temperatures were maintained, and satisfactory conditions of ignition and combustion existed. This result was obtained on two settings by merely providing a furnace not having a sudden increase of cross-sectional area, all other conditions remaining constant.

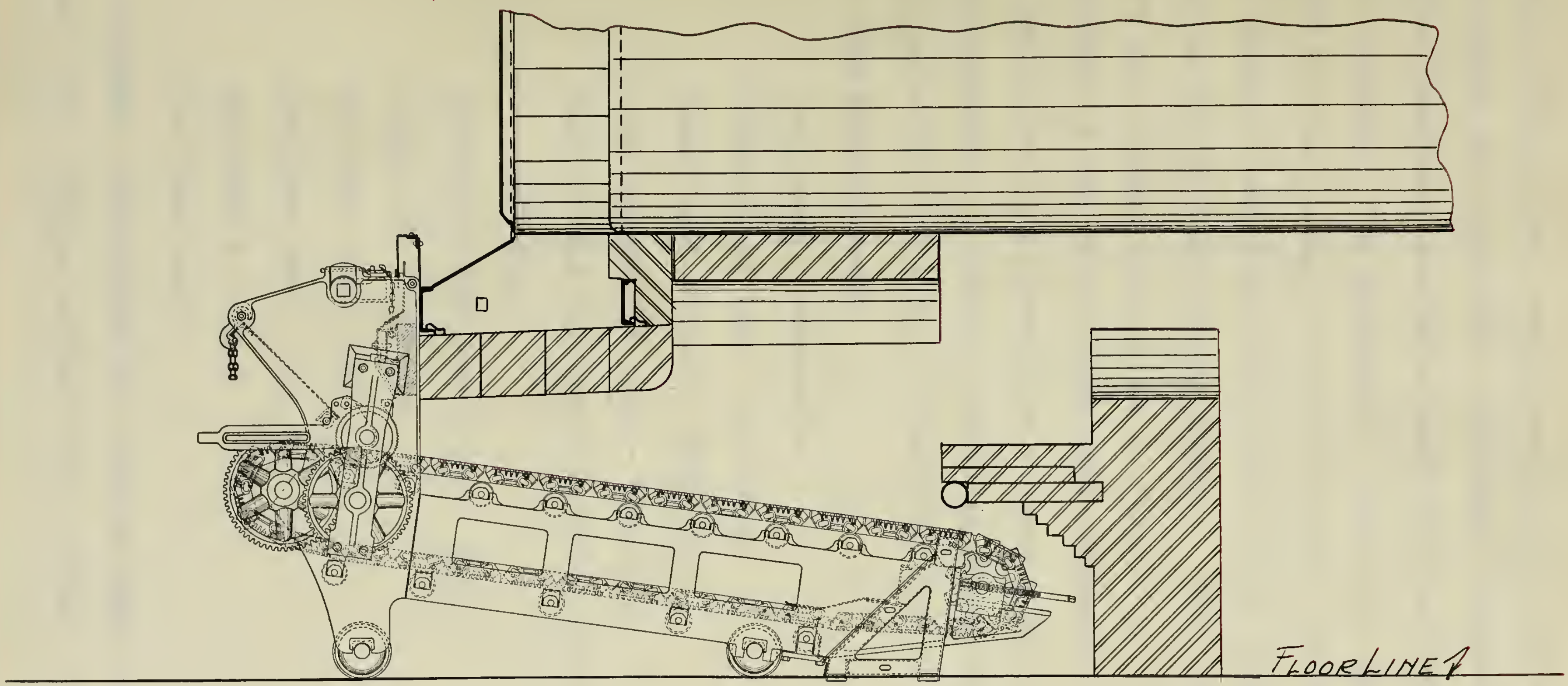
MODIFIED TYPES OF CHAIN GRATES.

The term Chain Grate usually implies horizontal grate surface. However, a type fast gaining in favor is the inclined type, Figure 23, having a grate surface approximately parallel to the tubes of standard horizontal water-tube boilers, or about 15 degrees. A stoker of this design may be used to good advantage under low set boilers, the advantage being that, because of the lower elevation of the rear section of the grate surface, more furnace room is provided, thus insuring better combustion, and because of increased height in front ash and droppage removal is facilitated.

Chain Grates for Caking and Coking Coals.

Coals of the class found in the districts of West Virginia and Eastern Pennsylvania cannot be handled on the ordinary type of Chain Grate, the reason being that the high per cent of resinous matter in the coal causes it, when heated, to cake into a solid mass, through which it is extremely difficult to induce air, and as a consequence the continuous ignition and combustion necessary to Chain Grate operation is prevented, and the fire becomes extinguished because of sheer lack of oxygen.

By constructing a furnace having a tile roof reversing the direction of the flames and causing the gases of combustion to pass forward toward the fresh, incoming coal, the item of ignition is mechanically provided for regardless of the condition of the fuel bed. This type of furnace combin-



RETURN TUBULAR BOILER
EQUIPPED WITH INCLINED TYPE OF CHAIN GRATE

FIG. 23

FIG 23

ed with a Chain Grate having oscillating plates over which the coal passes (See Figure 24) overcomes the caking and slow ignition features, and burns such coals as Pocahontas to a very fine ash. The principle is that the incoming fuel is ignited by the passage of the hot gases over its surface and when coking is completed the cake of fuel formed thereby is broken up by the oscillating plates. When this cake is once broken up, further combustion is carried on very readily and completely on the usual Chain Grate surface.

The writer has given this furnace a very thorough trial with Pocahontas, a typical run being given below. It is anticipated that this type of setting will be extensively used with Eastern coals.

Coal used - Pocahontas

Duration of test - 2½ hours

Total coal burned - 2205 lbs.

Coal burned per hour - 882 lbs.

Coal burned per hour per front foot of grate surface - 294 lbs.

Average draft over fire - .22"

Total ash - 123 lbs.

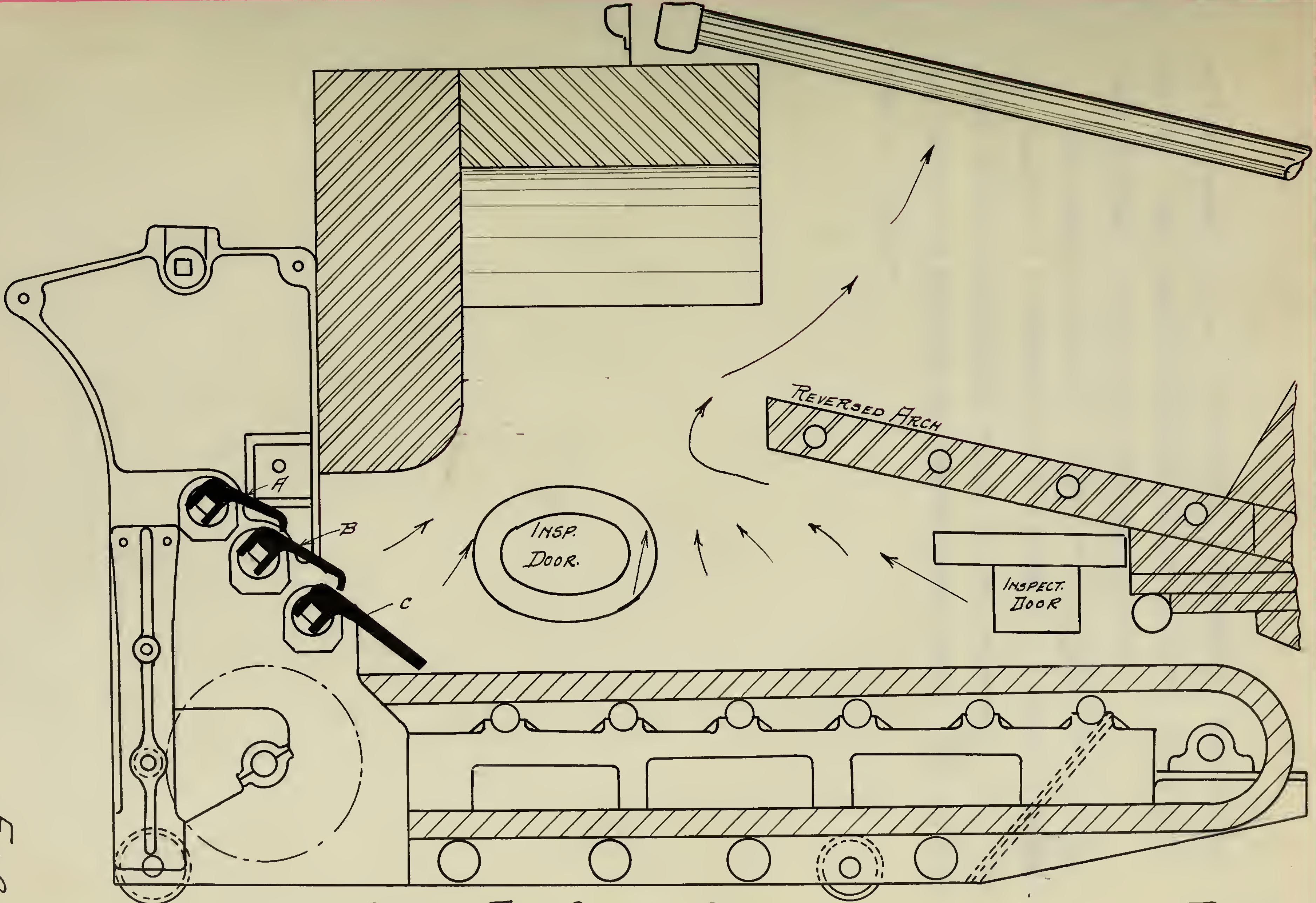
Per cent ash - 5½

Per cent CO-2 - 8.2

Per cent O - 11.2

Per cent CO- 0

Remarks: Throughout the test no smoke issued from the stack. The ignition effects were perfect. The caking effect



CHAIN GRATE FOR CAKING COALS

FIG 24.

FIG. 24

of the Pocahontas coal was entirely overcome by the tipping plates. The feeding mechanism worked uniformly and fed an even thickness of fire over the entire grate.

The era of scientific combustion has only begun. Much yet remains to be learned and discovered. If the preceding pages convey a successful record of past experience and present theory and practice as regards Chain Grates, the writer's hope is realized.

For literature bearing on the subject, reference is made to the following papers:

Some Performances of Boilers and Chain Grate Stokers with Suggestions for Improvements.- A. Bement.W.S.M.E.

How to Burn Illinois Coal Without Smoke - Bulletin No. 15, University of Illinois, L. P. Breckenridge.

The Suppression of Industrial Smoke with Particular Reference to Steam Boilers. - A. Bement W.S.M.E.

Some Characteristics of Coal as Affecting Performance of Steam Boilers. - W. L. Abbott. W.S.M.E.

The Significance of Drafts in Steam Boiler Practice. - Bulletin No. 367, U. S. Geological Survey - Walter T. Ray and Henry Kreisinger.